CROP RESIDUE DECOMPOSITION IN A SANDY SOIL AND ITS EFFECTS ON CORN GROWTH

By

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Dedicated to
my wife Maimunah Haji Ali,
my daughter Azantee Yazmie,
and my sons
Azrulteezal Azannee and
Amree Sharmal.

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Information on the cumulative effects of crop residue on fertility and management of Florida sandy soils in relation to crop growth is very scarce. Therefore, a research was conducted to evaluate the effects of crop residues [corn (*Zea mays* L.), oat (*Avena sativa* L.), rye (*Secale cereale* L.) and wheat (*Triticum aestivum* L.)] added at 0, 2.5, 5.0 and 7.5 mt/ha and inorganic N (0, 50, and 100 kg/ha) on soil properties and corn growth in three consecutive monocroppings in the glasshouse. The soil used was Mulat sand (Typic Ochraquults). Three laboratory incubation experiments were also conducted to study the decomposition of the residues by monitoring CO_2 evolution. Soil, residue types and rates and N rates used in the glasshouse study were identical with those in the laboratory study.

The greenhouse studies showed that plant dry weight yields were in the following order: Crop 3> Crop 2> Crop 1. In all three crops, soil pH was increased and 1 M KCl exchangeable soil Al was decreased by the crop residue treatment. Treatments effect on Mehlich I extractable soil nutrients (P, K, Ca, Mg, Fe, Cu and Zn) varied from crop to crop. The nutrient release was dependent upon the stage of residue decomposition. Other factors such as initial residue nutrient concentration, C:N ratio and the addition of inorganic N played an important role in mineralization and immobilization of nutrients (N and Mehlich I extractable) in the soil. Addition of 100 kg N/ha was sufficient for maximum growth with 5.0 mt/ha of corn residue, but the same amount of N was only sufficient for 2.5 mt/ha of all other types of residue. In Crop 3, the soil C:N ratio and bulk density were increased 13% and decreased 6%, respectively. In Crop 1, only P and K uptakes were increased by the residue treatments and N, Ca and Mg were not.

Laboratory incubation studies (60 days) indicated that total residue decomposition rate (CO_2 evolution) at 5.0 mt/ha was in the order of corn > oat > rye > wheat > control (no residue). In the second incubation experiment for every increment of 2.5 mt residue/ha, the decomposition rate was increased about 23%. While in the third experiment, for every 50 kg of N/ha added, the decomposition rate was increased about 12%. However, [illegible] the decomposition rate of soil organic matter.

It is suggested that among the four residue types corn is a better choice than oat, rye and wheat because it had higher nutrients concentration. Corn residue decomposed faster than the other three types of residue. Planting corn after 60 days of residue incorporation into the soil produced a maximum growth.

CHAPTER 1
GENERAL INTRODUCTION

Crop residues are the top portion of the plants which are not harvested. Usually, they are the remaining part of the plant left on the ground after the seed, fruit, stem or root has been removed. Due to the increasing costs of inorganic fertilizer production and the beneficial effects of crop residues added to the soil, agricultural researchers and farmers have realized that crop residues are a very valuable natural resource. If the residues are properly and efficiently managed, they can be a very important energy and nutrient source.

Among the several beneficial effects of returning crop residues to the soil are; reduction of soil erosion, (Skidmore and Siddoway, 1978), return of nutrients to the soil (Balasubramian and Nnadi, 1980), attenuation of soil temperature (Cruse, 1985), increased and/or maintenance of soil organic matter (Barber, 1979; Black, 1973 b), improvement of soil structure (Siddoway, 1963), increased soil water retention (Bond and Willis, 1969), generally increase crop yield (Ferguson, 1967), reduction of pollution (Fenster et al., 1978), improved drainage and infiltration (Fairbourn and Gardner, 1972), increased soil microbial population (Doran, 1980) and [illegible] (Carlson, 1985).

The disadvantages of leaving crop residues on the surface are that they serve as a breeding place for pests and diseases (Musick and Beasley, 1978; Williams and Wicks, 1978), produce phytotoxicity (Harper and Lynch, 1982; Patrick, 1971), cause weed control problem (Cook et al., 1978), leave a rough seedbed and require more seeds per land area to reduce stand loss (Guenzi and McCalla, 1962).

Residue management consists of leaving residue on the soil surface as in minimum tillage, burning residue in the field, removing residue, burning as an energy source or incorporation into the soil. Facts relating to crop residue soil incorporation which need clarification are: time of incorporation before planting, type of residue (source crop), nutrient release rate from residue and the effect of N fertilizer on the decomposition rate.

In view of the current increasing trend of multicropping and minimum tillage practice in the Southeastern United States (Lassiter, 1985), more and more crop residues are left on the ground after harvesting. The factors that affect residue decomposition need to be understood in detail. Parameters such as residue type, residue composition, quantity added to the soil, soil pH, plant nutrient release, temperature, soil water content, C:N ratio and soil aeration and their effect on crop growth need to be evaluated.

Although some studies such as the effectiveness of crop residues in controlling wind and water erosion, soil water retention, reduction of top soil reduction and decreasing/maintaining soil organic matter are well documented, information on the cumulative effects of crop residue decomposition on fertility and management of sandy soil is very scarce. Relatively little emphasis has been placed on the influence of residue types, residue rates, and N rates on crop residue decomposition in Florida sands.

Therefore, a series of experiments was conducted in the laboratory and glasshouse to study the crop residue decomposition in a sandy soil. The first study consisted of consecutive glasshouse experiments testing the effects of four residue types, four residue rates and three N rates on the changes in soil properties and corn (Zea mays L.) growth. The second study consisted of three laboratory incubation experiments (60 days each) comparing the different types and rates of residues with and without addition of N on soil-residue mixture decomposition rate by measuring CO_2 evolution. The purpose of the first laboratory experiment was to evaluate the decomposition rate of the four residue types [corn, oat (Avena sativa, L.), rye (Secale cereale, L.), and wheat (Triticum aestivum, L.)] at a fixed residue rate (5.0 mt/ha) without inorganic N added. The second experiment was conducted to compare the decay at four application rates (0, 2.5, 5.0, 7.5 mt/ha) of the same residues without an addition of inorganic N, and a third experiment was conducted to evaluate the effect of N rates (0, 50, and 100 kg/ha) on the decomposition of the same residues at a fixed rate, 5.0 mt residue/ha.

The overall thrust of the investigation was to provide quantitative information on the decomposition of corn, oat, rye and wheat residues in a sandy soil and on their effects on soil fertility and corn growth.

CHAPTER II
LITERATURE REVIEW

Plant Residue Composition

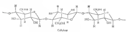
The two major components of plant residues are organic and mineral. Alexander (1977) divided the organic constituents of plant materials into six broad categories: (a) cellulose (15 to 60 dag/kg of the dry weight), (b) hemicellulose (10 to 30 dag/kg of the dry weight), (c) lignin (5 to 30 dag/kg of the plant), (d) water soluble fraction (including simple sugars, amino acids and aliphatic acids) (5 to 30 dag/kg of tissue weight), (e) ether and alcohol-soluble constituents such as fats, oil, waxes, resins and a number of pigments and (f) proteins (mainly N and S).

Alexander (1977) also estimated that the mineral constituents of plant materials by ashing was between 1 and 13 dag/kg of the total tissue. The water soluble constituents, proteins and mineral content decreased with maturity but cellulose, hemicelluloses and lignin increased.

Hausenbuiller (1978) identified three general groups of organic compounds in plant tissue namely carbohydrates, proteins and lignin. Four general groups of carbohydrates synthesized by plants are sugars, starches, hemicelluloses and cellulose. The simplest compounds are sugars, consisting of five or six C atoms arranged in short chains. All other carbohydrates are combinations of simple sugars, mostly of those having six C atoms.

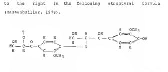
Cellulose is the most abundant organic component in plant tissue and hemicellulose is the second (Alexander, 1977; and Hausenbuiller, 1978). Cellulose and hemicelluloses are gradually accumulated in plant tissue especially in the straw of small grains and the stems of woody plants. These two carbohydrate compounds account in part for the stiffness acquired by maturing plant tissue.

According to Stacey (1976), cellulose is a remarkably pure organic substance consisting solely of units of glucose or grape sugar held together in a giant straight chain molecule. Hemicellulose occurs as much shorter molecule chains than cellulose and it is derived mainly from chains of pentose sugars which act as a cementing material holding together the cellulose micelles and fibrils. The chemical structure formula for cellulose is shown below (Morrison and Boyd, 1974).



Cellulose

Lignin is the third most abundant organic constituent of plant tissue (Alexander, 1977; Hausenbuiller, 1978). Lignin has a large and a very complex molecule containing C in six atom rings as well as in short chains. An important feature of the lignin molecule is the presence of -OH (Phenolic) groups which are linked to the C rings as shown to the right in the following structural formula (Hausenbuiller, 1978).



According to Hausenbuiller (1978) the H in the phenolic groups can be removed and replaced by Ca^{2+} , Mg^{2+} , K^+ , or other cations supplied by the base.

Larsen et al. (1978) reported the average N, P and K concentration in nine leading crop residues in the United States. The crops were barley (Hordeum vulgare L.), corn (Zea mays L.), cotton (Gossypium hirsutum L.), rice (Oriza sativa L.), rye (Secale cereale L.), sorghum [Sorghum bicolor (L.) Moench], soybean [Glycine max (L.) Merr.] and wheat (Triticum aestivum L.). The highest N content was in soybean residue (2.25 dag/kg) and the lowest was in rye (0.5 dag/kg).

Phosphorous was highest in cotton and soybean residues (0.22 dag/kg in each residue) and the lowest was in wheat (0.07 dag/kg). The K concentration was largest in oat (1.65 dag/kg) and smallest in rye (0.70 dag/kg). Larson et al. (1978) also reported that the total residues production by nine major crops in twenty states amount to 308 milion mt. These residues were estimated to contain 3.6, 0.5, and 3.7 million mt of N, P and K, respectively.

Staniforth (1979) summarized the N, P and K concentrations in wheat and straw. Nitrogen concentration in wheat straw ranged from 0.30 to 0.70 dag/kg, in rice straw from 0.45 to 0.50 dag/kg. Wheat and rice K concentration was between 0.83 and 1.86 dag/kg and 0.87 and 1.49 dag/kg, respectively. The P concentration of wheat straw was between 0.06 and 0.07 dag/kg, and in rice straw was between 0.05 and 0.10 dag/kg. He also showed that the range of Ca concentration in wheat, oat and barley straws were 0.12-0.25, 0.11-0.38, and 0.15-0.42 dag/kg, respectively. Sodium, Mg, Zn, Mn, Cu and S in wheat straw were in the range of 0.02-0.10, 0.06-0.09, 0.003-0.005, 0.002-0.003 and 0.03-0.04 dag/kg, respectively. The same elements were found in the oat straw in the range of 0.25-0.35, 0.07-0.12 dag/kg for Na and Mg, respectively and 0.013, 0.0015, 0.0004 and 0.076 dag/kg for Zn, Mn, Cu and S.

Another report (Fenster et al., 1973) showed that the average composition of wheat straw was 90 dag dry matter/kg, 0.67 dag N/kg, 0.07 dag P/kg, 0.97 dag K/kg and 0.17 dag Ca/kg. Robertson (1977) found that the average N, P and K returned to a Florida soil in corn, soybean, oat and peanut residues were 37, 19, 58 dag/kg, respectively. Among these residues, peanut (Arachis hypogae L.) had the highest N, P and K concentration 54, 31 and 71 dag/kg and soybean straw only contained 17, 10 and 26 dag/kg.

Pathak et al. (1986) characterized the properties of ten crop residues including density, equilibrium moisture content, calorific value, cellulose, pentosan, lignin, C, H, N, Na, K, P, Mg, Ca and SiO concentration. The residues they used were Arhar stalks, bagasse, cotton sticks, Dhaincha stalks, peanut shell, maize cobs, maize stalks, rice husk, rice straw and wheat straw. They observed that the cellulose concentration of all residues was over 35 dag/kg. The pentosan concentration varied more widely than the cellulose. Lignin concentration also varied very widely. In general, the woody residues had a higher lignin concentration than the non-woody residues. Analysis of these residues showed that the C concentration varied from 36.8 to 53.3 dag/kg. Sodium and Mg were highest in rice straw. Potassium concentrations were relatively high in many residues and P concentrations were below 0.1 dag/kg in all residues except in peanut shell. Silica contents were high (more than 5.0 dag/kg) in rice straw, rice husk and wheat straw. Large amounts of Si were also reported in rice and wheat straws (Jackson, 1977; and Tanaka, 1973).

Effects of Residue Management on Crop Yields

The long and short term effects of adding crop residues to the soil on crop yields have been studied by many researchers (Black, 1973 a; Black and Siddoway, 1979; Doran et al., 1984; Ferguson, 1967; Smika et al., 1969; Wilhelm et al., 1986). Ferguson (1967) reported that after 8 yr of repeated application of straw with continuous cropping, wheat and oat yields increased. The treatments were 0, 4484 and 8967 kg residue/ha. The study was conducted for 10 yr on Miniota sandy loam soil in Canada. The wheat yields with 0, 4484 and 8967 kg straw/ha were 0.85, 0.89 and 1.21 Mg/ha respectively. The oat yields for the same treatments were 1.46, 1.58 and 1.89 Mg/ha. However, the yields were only increased by treatments after eight yr of residue application.

Smika et al. (1969) studied the effects of straw mulch on wheat grain yield in Colorado, Nebraska, and Montana over six yr period from 1962 through 1968. Their studies showed that the yields were positively correlated with soil water content at seeding. Soil water content at seeding was increased with increasing straw mulch rates. The straw mulch rates applied were 1680, 3360 and 6720 kg/ha. Their studies which were conducted in the semiarid Central and Northern Great Plains showed that the beneficial effects of straw mulch on wheat yields were primarily due to the increase in soil water content.

A study on the effect of annual additions of green rye, wheat straw, alfalfa (Medicago sativa) leaves, peat muck and manure to Uplands sand and Rideau clay soil for 20 yr was reported by Halstead and Sowden (1968). The addition of these materials to the soils had the greatest effect on yield and on uptake of N and P by oat. The average yields of 11 crops with these materials as treatments were higher on the sandy soil than clay soil. They concluded that the yield increases were due to the increased NO_3 production, organic P concentration, enzyme activity, cation exchange capacity, organic C and extractable K contents in the soil.

Black and Siddoway (1979) observed an increase in wheat grain production over the check as a result of previous residue treatments. The respective yield increases due to the treatments of 1680, 3360 and 6730 kg residue/ha and without fertilizer were 0.18, 0.28 and 0.59 Mg/ha. However, when N and P fertilizers were added with these residue rates, the respective treatment yield increases were 0.27, 0.57 and 0.74 Mg/ha. The check plot (surface residues removed and no fertilization) yield was 2.90 Mg/ha.

A recent report by Wilhelm et al. (1986) stated that there was a positive linear response between the grain and stover yields of corn and soybean and the amount of residue applied to the soil surface. Each Mg/ha of residue removed decreased grain yield about 0.10 Mg/ha and stover yield by about 0.30 Mg/ha. Their study also indicated that the response of applied residue accounted for 81 and 84% of the variation in grain yield of corn and soybean, respectively. The percentage of variation in stover yield due to the quantity of applied residue were 88 and 92% for corn and soybean. They concluded that the effects of residue on crop yields were induced mainly through the changes in soil water and soil temperature.

An 8 yr study of the effect of residue on wheat yield grown on a sandy loam soil (Typic Argiborolls) was reported by Black (1973 b). Without fertilization, the average grain yields for treatments 0, 1680, 3360 and 6730 kg residue/ha were 1.50, 1.57, 1.57 and 1.63 Mg/ha, respectively. The average yields for the same treatments with fertilization were 1.72, 1.76, 1.84 and 1.91 Mg/ha. His study which was conducted in Montana also found that the 8-yr average wheat dry matter productions at tillering, heading, and maturity were not affected by the residue treatments.

Barber (1979) evaluated the effects of removing the residue, returning the residue and doubling the rate of returned residue on soil organic matter content and corn yield. Continuous corn was grown for 11 yr. He found that corn grain yields were not affected by the treatment, but soil organic matter was increased especially in the double residue returned treatment. Results of Barber (1979) and Wilhelm et al. (1986) were contradictory. Wilhelm et al. (1986) found an increase in corn grain yield when residue was returned to the soil. They also reported that soybean yields were higher in the residue returned than in the residue removed treatment.

Doran et al. (1984) evaluated the effects of various amounts of surface crop residues on dryland production of no-tillage corn, grain sorghum, (Sorghum bicolor L.) and soybean. The study was conducted for 3 yr in Eastern Nebraska. They observed when crop residues were completely removed after harvest, average grain and residue yields of corn and soybean were 22 and 24% lower, respectively, than where residues were not removed. Sorghum yields were unaffected by residue removal but stands were less at the 150% residue rate. Sorghum was more tolerant to water and temperature stress conditions than corn and soybean. Their results also showed that the removal of surface crop residues can seriously reduce corn and soybean yields in climates where stressful conditions occur during the growing season. Other workers, Fenster et al. (1978), also agreed with the results of Doran et al. (1984). Fenster et al. (1978) stated that removal of crop residue decreased corn yield about 0.19 Mg/ha, oat yield about 1.18 Mg/ha and wheat yield about 0.13 Mg/ha.

Morachan et al. (1972) reported a 13 yr study on the effects of alfalfa (Medicago sativa L.), cornstalks, sawdust, oat straw and bromegrass (Bromus inermis Leyss) residues on corn yield. The amounts they applied were from 0 to 16 mt/ha/yr. During the first 9 yr grain yields were found to be lower than the check and sawdust treatments as compared to all other residues. They also observed that during the last 4 yr grain yields declined sharply with the rate of addition of cornstalk residues and slightly decreased with the addition of alfalfa. They suggested that the yield decline in the cornstalk treatment was due to a lowering of soil pH and an Al-induced Ca deficiency in the plant.

Researchers in Mississippi reported a yield increase in grain sorghum and soybean as a result of the proper management of crop residues [Hairston et al. (1984); Hovermale (1983), Sanford and Hairston (1982); Sanford and Hairston (1984)]. Hovermale (1983) also observed that soybean grown in wheat, ryegrass (Lolium perenne L.) and oat residue were taller than those grown in crimson clover (*Trifolium incarnatum*) residue.

For 14 yr, Undersander and Reiger (1985) studied the effects of wheat straw management on irrigated winter wheat in Texas. Their treatments were 1) residue incorporated into the soil, 2) residue mechanically removed, and 3) residue burned. The average grain yields for the incorporated, removed, and burned treatments were 3.37, 3.27 and 3.41 Mg/ha, respectively. There was no yield difference among the treatments.

The effect of residue on crop performance in the temperate area can be negative because of lowering soil temperature under residue cover. Cruse (1985) reported that the residue cover could delay crop emergence after planting and result in yield reductions.

A search of the literature shows that crop residues did not always increase yields in the Northern United States. However, in areas where the early season soil temperatures are not too low and in semiarid areas crop yields have been increased by residue management. A few research reports before 1962 show gains in corn yield due to surface residue, Horst and Mederski (1957) 10%, Duley and Russel (1948) 100% Duley (1960) 43%, and Parker and Larson (1962) 13% increase. Yield increases vary from yr to yr and depend on the rainfall, soil temperature, land slope etc.

The effects of residue on crop yields under different tillage management systems are different. Aulakh et al. (1984) showed that under zero tillage, wheat grain yield was increased 16% by addition of 3,000 kg straw and under conventional tillage the yield of the same treatment was reduced by 50%. They attributed the yield reduction to the immobilization of mineral N. They also speculated that the yield increase under zero tillage was probably due to the conservation of soil water under a thick continuous layer of straw. Gallaher (1980) and Karlen et al. (1984) supported the idea that yield increases under residue mulch treatment were due to the conservation of soil water. Karlen et al. (1984) also found that without supplemental irrigation water, corn grain yields were lower for the treatment where 90% of the stover was removed than the treatment where all residues were left on soil surface.

The effects of residue on crop yield can be positive or negative depending on location, environment and management practices. In many cases crop yields were increased in the semiarid area, when residues were left on the soil surface (Black, 1973 b; Smika et al., 1969; Wilhelm et al., 1986). Increases in soil water content and reduction of surface soil temperature in the semiarid area as a result of leaving residues on the ground were the benefits that contribute to the increased crop yields. Long term effects of residue returned to the soil may include improved soil physical, chemical and microbial properties and increased crop yield.

Effects on Soil Properties and Fertility

Soil physico-chemical and microbiological properties were changed when crop residues were added to the soil (Black, 1973 b; Ferguson, 1967; Maracham et al., 1972). During the short term, the effect of addition may not be significant. However, continuous addition of residues into the field increased soil organic C, total soil N, N mineralization, exchangeable K and soluble P (Black and Siddoway, 1979). The positive influence of increasing crop residues on surface soil organic C has also been observed by other workers: Black (1973 b); Ferguson (1967); Gelisher (1980); Johnson (1950); Mathews (1945); Oveson (1966); Rasmussen et al. (1980) and Unger (1968).

Pikul and Allmaras (1986) reported that the treatment of straw plus 22 Mg/ha of strawy manure incorporated into the soil resulted in a higher surface soil pH and organic C content compared to treatments a) wheat straw b) straw burned in fall and c) straw plus 90 kg N/ha. Soil bulk density was lowest for straw plus 22 Mg straw manure/ha compared to the other three treatments. In their study, they also observed that crop residue management and fertilization with NH_4^+ base fertilizer has had marked effect on soil pH in the Ap horizon. Soil pH decreased with decreasing organic C addition for the treatments without inorganic fertilizer.

The effect of corn stover and manure application on soil organic matter was studied by Ketcheson and Beauchamp (1978). They found that corn stover and manure applications increased soil organic matter slightly over the stover-removed treatment (3.9 vs 3.7 dag/kg). Increases in soil organic matter content due to the addition of crop residues was also reported by other researchers: Barber (1979); Black (1973 a); Hooker et al. (1982); and Larson et al. (1972).

The relative increase in organic C content was greater in sandy soil than in sandy loam soil (Bhatnagar et al., 1983). Barber (1979) estimated that about 8 to 11 dag of C/kg of corn residue was synthesized into new organic matter in a silt loam soil. In Florida, Gallaher (1980) reported that after 10 yr of vetch (*Vicia villosa*) and rye mulched treatments, soil organic matter (O.M.) was increased from 1.5 to 2.6 dag O.M./kg soil and total N from 0.047 to 0.069 dag N/kg soil. He also mentioned that the degree of soil aggregation was higher in the residue treatment than without residue.

Other researchers also reported that the water stable soil aggregates were higher in residue treatments than without residue (Ketcheson and Beauchamp, 1978; MacKay and

Kladivko, 1985; Morachan et al., 1972). Siddoway (1963) reported an increase in dry aggregate soil structure with increasing residue levels. Another report (Black, 1973 b) shows that the erodible soil fraction was reduced from 50.5% in non-residue treatment to 27.5% when 6730 kg wheat residue/ha was added to the soil. Increasing the amount of residue returned to the soil can effectively increase soil aggregate stability.

The effect of crop residue rates on surface soil bulk density has not been clarified. Some reports show that the bulk density of the surface soil was reduced when residue levels were increased (Black, 1973 b; Black and Siddoway, 1979; Kashi and Fryrear, 1973; Mathew, 1945). Other researchers, Bhatnagar et al. (1983), Hedge et al. (1982) and Ketcheson and Beauchamp (1978) found no effect of crop residues on soil bulk density.

Other soil physical properties such as soil water storage, hydraulic conductivity, infiltration rate and soil temperature are also affected by crop residues added to the soil. Soil water storage was found to be higher under residue than without residue (Blevins et al., 1983, Moody et al., 1963; Morachan et al., 1972; Unger, 1978). Greb et al. (1967, 1970) found that precipitation stored as soil water ranged from 16 to 26% under no residue and 31 to 37% when 6720 kg of wheat straw/ha was left on the soil surface.

Another report by Black (1973 a) shows that the average of plant available water stored in soil was positively correlated with mt/ha of surface residue. Available soil water within root zone was increased about 0.5 cm for each metric ton of residue. The report also mentions when precipitation was above average, the influence of surface residue on soil water storage was nullified.

A laboratory experiment conducted by Fairbourn and Gardner (1972) indicated that the vertical mulch treatment on a level soil surface saved 30 to 40% of the applied water. The efficiency of water storage with vertical mulch was reduced by 17% when the surrounding soil surface was wet. The positive influence of crop residue on soil water storage in the field has been observed by many researchers (Black, 1973 a; Bond and Willis, 1971; Moody et al., 1963; Smika et al., 1969; Unger and Wiese, 1979).

Surface soil temperature is reduced when residues are placed on the soil surface. Moody et al. (1963) reported the mean daily soil temperature at 10 cm depth remained lower under mulch than unmulched surface throughout a summer season. Increasing the amount of crop residues on soil surface reduced the average soil temperature and retarded the warming of the soil. This was due to the insulating and reflecting effects of the residue on solar radiation. The reduction of surface soil temperature under residue mulch was also reported by other workers (Adams, [illegible]; Black, 1970; Burrows and Larson, 1962; Gupta et al., 1981; Onderdonk and Ketcheson, 1973; Singh et al., 197[illegible]; Van Wijk et al., 1959; Willis et al., 1957).

In temperate regions, Allmaras et al. (1973) observed when soils were warming, the average reduction of soil temperature at 10 cm depth was between 0.15 and 0.30 °C for each 1 Mg/ha of small grain residue applied to the soil surface. While in a semiarid tropical environment, where extreme temperatures often reduce crop yields, Lal (1974) reported an 8°C reduction in soil temperature at 5 cm depth when 2 Mg residue/ha was applied.

Maintaining crop residues on the soil surface also increases infiltration rates (Mannering and Meyer, 1963), reduces surface runoff (Greenland, 1975), reduces evaporation rates (Bond and Willis, 1969) and increases entrapment of snow (Willis et al., 1961). The average percentage of infiltration ranged between 43-45% and 52-66% for without-straw and with-straw treatments, respectively (Brown, 1985).

The sorption and desorption characteristics of P in soil are affected by the addition of organic residues. Singh and Jones (1976) reported that residues which contain less than 0.3% P (sawdust, wheat straw and corn stalks) decreased labile soil P and increased P sorption by the soil after 75 days incubation. Residues containing more than 0.3% P (alfalfa, barley (*Hordeum vulgare*), bean (*Phaseolus vulgaris*), and poultry manure) decreased P sorption after the same period of incubation. The effect of various organic farm products (maize stalks, compost, poultry manure) on soil available P was also studied by Izza and Indiati (1982). They found that incorporation of these materials in the low P fixing capacity soil increased soil available P. The P concentration in organic farm products they used ranged from 0.03 to 1.37 dag/kg.

The cummulative effects of increasing quantities of organic residues on available nutrients in soil for 11 consecutive yr were studied by Larson et al. (1972). They reported that addition of 16 tons/ha plant residues/yr to the soil increased the amount of N, S, and P 37, 45, and 14%, respectively, over the control (no-residue) treatment. They also found that the NH_4-N production, weak-acid soluble P and exchangeable K in the soil were increased as a result of increasing addition of organic residues.

Solubilization of Mn and Fe in soil was affected by wheat straw and alfalfa amendments (Elliot and Blaylock, 1975). The release was greater for Mn than Fe and also much higher at 30 kPa than 50 kPa moisture tension. The release of Mn and Fe from the soil columns was in the order of alfalfa > wheat straw > soil alone. They suggested that the potential accumulation of soluble N in a well-drained soil was possible where there was a large quantity of plant residues incorporated into the soil.

A recent study in Australia by White (1984) found that incorporation of crop residues into "Black Earth" soil depressed NO_3-N within 0-20 cm depth but the effects on NH_4-N and P were unclear. He also observed the soil nutrient concentrations were highly correlated with stubble C:N ratio and most coefficients were negative.

In the Pacific Northwest, Douglas et al. (1980) reported that the method of placement, composition of residue and loading rate were important factors influencing mineralization or immobilization of N and S. Net N mineralization in buried straw varied from 2 to 17 kg N/ha as straw composition varied from 0.20 to 0.78 dag N/kg residue. When placed above or on the surface net N mineralization ranged from -4 to 6 kg N/ha with the same straw composition. Net S mineralization was similar to N mineralization but magnitudes were smaller. A higher mineralization of N was observed at 4 cm soil depth as compared to the surface was also observed by Cochran et al. (1980) and Brown and Dickey (1970). Immobilization on NO_3-N in the surface soil under wheat straw mulch was also reported by Smika et al. (1969).

A study on the release of P from white clover (*Trifolium repens*) residue in high and low P status soils was reported by Blair and Boland (1978). Their results suggested that the addition of plant material resulted in immobilization of soil P only in the low P soil in the absence of plants. In the high P soil no immobilization of P was observed.

The above reviews show that soil properties and fertility were affected by the management of crop residues. Soil organic matter/organic C , soil N, water stable aggregates, bulk density, water storage, hydraulic conductivity, infiltration rate, surface soil temperature, evaporation, sorption and desorption of P, mineralization and immobilization of N, P and S, solubilization of Mn and Fe, CEC and pH are all affected by the residues.

Factors Affecting Decomposition

Interrelated factors which affect the decomposition of crop residues are aeration, moisture, temperature, availability of nutrients essential for microbial growth and composition of the residue (Hausenbuiller, 1978). In addition to the factors given by Hausenbuiller (1978), Parr and Papendick (1978) mentioned that pH, C:N ratio and age of plant materials also influence the crop residue decomposition.

Jenkinson (1981) in his review article stated that there are seven factors influencing the decomposition of plant and animal residues in soil. Those factors are moisture, O_2 (aeration), soil pH, inorganic nutrients, temperature, clay content, particle size of the residue material, soil animals and placement depth. However, experimental data available in the literature indicate that temperature, moisture, C:N ratio and location on or within the soil profile are the most important factors (Reddy et al., 1980).

Waksman and Gerretsen (1931) were pioneer researchers who studied the influence of temperature, moisture, and available N on the decomposition of oat straw. They reported that the optimum temperature for the decomposition was 37°C. Temperatures below 7°C reduced the rate of decomposition. Their data also showed that the addition of inorganic N hastens the decomposition of plant material as a whole especially of the hemicelluloses and cellulose. Nitrogen had very little effect upon the decomposition of the lignin.

A recent study by Roper (1985) in Australia in the effects of moisture and temperature on wheat straw decomposition in two soils showed that the straw decomposed over a wide range of temperatures. It was 20-50°C for Gunnedah soil and 15-45°C for Cowra soil. The optimum moisture level was at 0.3-2.0 times greater than moisture level at 10 kPa water content for both soils.

An investigation by Ivarson (1973) in Canada indicated that for each 1°C drop in soil temperature, the rate of decomposition decreased approximately 1.8%. He also estimated the rate of loss of 3,000 kg of leaf litter/ha during 6 months at 10, 4, and 1°C would be 660, 420 and 270 kg/ha/yr, respectively.

A laboratory study by Ruiz-Gimenez and Chase (1984) indicated that the decomposition rate of wheat straw was not affected by fertilizer ammendment and length of straw cuttings, but it did increase when soil depth was decreased. Their results also showed that the decomposition rate was decreased when the quantity of residue added was increased two to five fold. Similar results on the effect of residue loading rate to the soil were observed by other workers (Broadbent and Bartholomew, 1948; Brown and Dikey, 1970; Hallam and Bartholomew, 1953).

An investigation by Mass and Adamson (1972) on the effect of the addition of nutrient solutions on the decomposition of sawdust showed that nutrient solutions containing fairly low levels of N, P, and K increased the rate of decomposition. However, the particle size of sawdust did not influence the rate of decomposition.

Soil pH is one of the factors which controls microbial population and residue decomposition. Each bacterium, fungus and actinomycete has an optimum pH for growth (Alexander, 1977). Decomposition typically proceeds more rapidly in neutral than in acid soils. The pH governs the type of microorganisms which are dominant in the C cycle of any habitat. Pikul and Allmaras (1986) reported that crop residue management profoundly affected soil pH within 0.40 m depth. They observed that soil pH decreased with decreasing C addition and concluded that soil organic matter buffers against pH change by the adsorption and inactivation of H ions. The optimum pH range for rapid decomposition of various organic wastes and crop residues is 6.5 to 8.5 (Parr and Papendick, 1978). Jenkinson (1977 b) found that ryegrass decomposition was initially slower in a strongly acidic soil (pH 3.7) but by the end of 5 yr the difference between this soil and other soils (pH 4.9 to 8.1) had nearly dissappeared.

The importance of C:N ratio of plant material in determining the rate of decomposition is well known (Brown and Dickey, 1970; Hendrickson, 1985; Parker, 1962; Parr and Papendick, 1978; Reinertsen et al., 1984; Smith and Douglas, 1971). The N immobilization potential of organic materials has been assessed in terms of their C:N ratios. When crop residues with narrow C:N ratios (20:1 or less) are incorporated, N will be mineralized. Residues with wider C:N ratios (30:1 or more) will immobilize N at least temporarily (Tisdale et al., 1985). The C:N ratio in plant material is variable, ranging from 20:1 to 30:1 in legumes and farm manure, 100:1 in certain strawy residues and as high as 400:1 in sawdust (Brady, 1984).

Bartholomew (1965) and Parr and Papendick (1978) caution against the use of C:N ratios because they are valid only when the C and N are readily available to the microorganisms. Bartholomew (1965) suggested that the N concentration of crop residues might be a better measure of N availability with the critical concentration being between 1.0 and 1.3 dag/kg by weight. Previous research has shown that the addition of inorganic N to residues enhanced the decomposition rate of the residue in soil particularly those which had high C:N ratios (Waksman and Gerretsen, 1931; Alexander, 1977; Allison and Cover, 1960). However, recent reports showed that the residue decomposition was mainly affected by the available C and N rather than total C and N in the residue (Smith and Peckenpaugh, 1986; Dawson and Elliot, 1986; Reinertsen et al., 1984). Addition of N to low-N residues generally hastened decomposition when conditions for decomposition were favorable, but if low temperature or insufficient moisture limited decomposition, N would not necessarily stimulate decomposition (Smith and Douglas, 1971).

Increasing rates of N did not increase the overall decomposition rates of crop residues studied by Knapp et al.

(1983 b). They postulated that the turnover of substrate and microbially associated organic N result in decomposition of crop residues even under presumably N-deficient conditions. Harmsen and Van Schreven (1955) mentioned in their review paper that numerous investigators agree plant materials must contain at least 1.5 to 2.0 dag/kg N in the dry matter which corresponds to a C:N ratio of 20 to 25, before N can be mineralized.

Studies comparing top and root decomposition have provided conflicting results. Jenkinson (1977 a) found similar decomposition rates for ryegrass tops and roots during a 155-day study. Ladd (1981) reported that the rate of wheat straw and root decomposition was nearly equal, but medic (Medicago littoralis L.) roots decomposed more slowly than the stems and leaves. When Smith (1966) studied wheat straw and root decomposition, he reported that roots decomposed more slowly because they contributed more to the residual C than the straw. Proximate analysis had been useful for comparing the decomposition of different residues based on their chemical composition (Herman et al., 1977; Waksman and Tenney, 1929). In general, the greater the proportion of lignin in the residue, the slower the rate of decomposition (Alexander, 1977). A recent study by Jawson and Elliot (1986) supported the idea that under a nonlimiting nutrient condition, differences in decomposition between plant parts reflect the difference in residue composition at the initial stage of decomposition.

Drying and rewetting also promoted the decomposition (Asato et al., 1984; Birch, 1958). The longer the time moist following drying, the greater the decomposition. The more frequent the drying and wetting cycles, the greater the decomposition. Drying and wetting affects soil aeration. The effects of aeration on organic matter decomposition were significant. It was observed that the breakdown was slower under anaerobic than under aerobic conditions (Acharya, 1935; Reddy and Patrick, 1975; Tenny and Waksman, 1930).

Soil earthworm (*Lumbricus rubellus*) population has been shown to facilitate the breakdown of crop residues. MacKay and Kladivko (1985) reported that 60% of original soybean residues were recovered when no earthworms were added, whereas in the presence of earthworm only 34% of the residues remained. For maize residues 85% and 52% were recovered from treatments without earthworm and with earthworm, respectively.

CHAPTER III

GLASSHOUSE STUDIES ON THE EFFECTS OF APPLIED CROP RESIDUE AND N ON SOIL PROPERTIES AND CORN GROWTH

Introduction

Many short term crops such as wheat (Triticum aestivum L.), oat (Avena sativa L.), rye (Secale cereale L.) and corn (Zea mays L.) can be grown on Florida sandy soils. Increasing emphasis is being placed on minimum tillage farming in this area. Minimum tillage systems increase the amount of crop residues on the soil surface. It has been predicted that 65% of the seven major annual grain crops of the United States will be grown by the minimum tillage system by the year 2000 (USDA, 1975).

Usually farmers incorporate the residues into the soil or leave them on the surface. Some states require farmers to incorporate crop residues into soils after harvesting. Little attention has been given to characterizing the effect of various types and application rates of crop residue on soil properties and plant growth on sandy soils under Florida conditions.

The questions of interest in this research were how long should the residue be allowed to decompose in order to produce maximum yield? how much residue should be applied or returned to get optimum results?, and does incorporation of residues improve soil fertility or degrade it?

If a farmer has a choice in the use of crop residues, what kind of residues should he use, which residues decompose faster, and how do they affect crop performance. A study on the incorporation of corn residue into a red sandy clay soil showed that corn grain yield, soil organic matter content and available K concentration were increased, but N, P concentrations, bulk density and infiltration rate were not affected (Hedge et al., 1982).

The hypotheses of these studies were as follows. 1) fertility status of a sandy soil should be improved by the addition of crop residues, 2) plant growth should be increased more in a soil with highly decomposed crop residues than in the soil with partially decomposed residues, and 3) an addition of N into the plant residue and soil mixture should enhance the residue decomposition by lowering its C:N ratio. Therefore, the objectives of this study were i) to evaluate the effects of different types and amounts of crop residues (wheat, oat, rye and corn) combined with inorganic N on the fertility of a sandy soil and 2) to compare the growth performance of corn in three consecutive monoculture crops as affected by the incorporation of the residues.

Materials and Methods

Analysis of Soil and Crop Residues

Soil samples used in this study were taken from the Horticultural Unit Experimental Farm near the University of Florida, in Northwest Gainesville, Florida (Latitude 29°4' N, Longitude 82°20' W). The samples were taken from the Ap horizon (0-15 cm) of a Mulat sand (coarse-loamy, siliceous, hyperthermic, Typic Ochraaquults). This soil commonly has a seasonal fluctuation of the ground water table within 1 m depth and mean annual temperature at the 50 cm depth is greater than 22°C. This type of soil commonly occurs along the Atlantic coast on low marine or river terraces of the late-pleistocene age (Soil Survey Staff, 1975).

Soil samples were air dried and sieved through a 2 mm diameter Al screen before analysis. Partical size analysis, water retention at 1.0, 3.3 and 150 MPa pressure, pH (in H_2O and 1 M KCl), cation exchange capacity (CEC) at pH by NH_4OAc, effective cation exchange capacity (ECEC) in 1 M KCl, organic C, total N, Mehlich I (0.05 M HCl + 0.0125 M H SO) extractable nutrients (P, K, Ca, Mg, Fe, Cu, Zn) and clay mineral identification by X-ray diffraction analysis (Whitting, 1965) were performed. The hydrometer method was used for particle size analysis. Water retention characteristics were determined by a ceramic pressure plate apparatus (Richards, 1965). A glass electrode pH meter

(Orion Research Model 901 A/digital ionalyzer) was used at a 1:2 soil to solution ratio for both water and 1 M KCl pH. Soil organic C was determined by the Walkley-Black wet oxidation method (Allison, 1965) and total N was determined by the semimicro Kjeldahl method (Bremner, 1965).

Mehlich I (Mehlich, 1953) extraction for nutrients in sandy soils and their interpretations as described by Rhue and Kidder (1983) was followed. The extraction solution was used in a 5 g : 20 ml soil to solution ratio, shaken for 5 minutes and filtered through Whatman no. 40 filter paper. The filtrate was saved for P, K, Ca, Mg, Fe, Cu and Zn analysis. Phosphorus was determined by calorimetry, K by flame emission spectrophotometry and other elements were analyzed by atomic absorption spectrophotometry at the Institute of Food and Agricultural Sciences (IFAS) Analytical Research Laboratory, University of Florida.

Four types of the most common and abundant crop residues (corn, oat, rye and wheat) were used in this study. The mature crop residues were taken from farmers fields near Live Oak, Florida (Latitude 30°20'N, Longitude 83°00' W). These residues were collected immediately after grain harvest. They were dry when taken from the field and kept in plastic bags.

Before these residues were incorporated into the soil, they were chopped into 1 to 2 cm lengths. Subsamples of the residues were ground to pass a 2 mm screen in a Wiley mill in preparation for elemental analysis. Total C in the plant residues was determined by wet-oxidation technique of Shaw (1959). The oxidation was carried out by heating the samples (0.5 g each) with a mixture of $K_2Cr_2O_7$, H_2SO_4 and H_3PO_4 for 10-15 minutes and the CO_2 liberated was determined gravimetrically after absorption in soda-lime.

A one gram sample from each residue was ashed in a muffle furnace at 250°C for 30 minutes, and then the temperature was increased to 500°C for at least 2 hours until the ash was white. Ash solution samples were prepared by digestion with 6 M HCl on a hot plate. Four subsamples of each residue were analyzed. The ashed samples were diluted to 50 mL in a volumetric flask after an addition of 2.25 mL of 6 M HCl. The final concentration of HCl in the sample solutions was 0.27 M. An atomic absorption spectrophotometer was used to determine the residue concentration of Ca, Mg, Fe, Cu, and Zn. Phosphorus and K were determined by calorimetry and flame emission spectrophotometry, respectively. These instruments were located at the IFAS Analytical Research Laboratory, University of Florida. Residue total N was determined by the method of Nelson and Summers (1973).

Crop 1

The greenhouse experiment was carried out as a factorially arranged randomized complete block design. A total of 48 treatment combinations (4x4x3) and 3 replications was employed. Residue types used were corn, oat, rye and wheat. Residues were applied at 0, 2.5, 5.0 and 7.5 mt/ha. These rates represent the range which can be produced and returned to the soil by these crops. Residues were incorporated in the soil prior to Crop 1 only. Applied N rates were 0, 50, and 100 kg N/ha as NH_4NO_3.

Black plastic, 3 L pots were filled with 2 kg of air-dry soil (< 2mm). Each pot size was 16.5 cm height and 16.0 cm top diameter. Clean gravel (prewashed with HCl and deionized water) was placed at the bottom of the pot about 4 cm deep before filling with soil. A layer of cheese cloth was placed on top of the gravel to prevent the soil from reaching the bottom of the pot.

Chopped residue fragments (1 to 2 cm length) were incorporated thoroughly into the soil according to predetermined rates. Deionized water was added to bring the soil to 7% water content by weight basis. Uniform moisture was maintained through periodic weighings and water addition. Inorganic N fertilizer (NH_4NO_3) was added in solution at specified rates (0, 50 and 100 kg/ha). Field corn seeds (cultivar Pioneer Brand 3059') were treated with the fungicide Captan (N- [(Trichloromethyl thio] -4- cyclohexene -1,2 -dicarboximide) before they were germinated on moist cheese cloth in the laboratory.

Pregerminated corn seeds were transplanted into the pots on 6 November, 1984 when the radicles were about 2 cm in length. Each pot received 4 seedlings. On the same date 75 kg K/ha as K_2SO_4 in solution was added to the pots. Initially P was not added because according to the interpretation by Rhue and Kidder (1983) the amount of Mehlich I extractable P (93 mg/kg) was considered adequate for the growth of an agronomic crop such as corn. The plants were thinned to a single plant/pot at one week after planting.

About one month after planting, a severe P deficiency was observed on all plants. Plants were stunted, very dark green in color with reddish purple leaf tips and margins. On 8 December, 1984, 75 kg K/ha and 50 kg P/ha were applied as K_2SO_4 and Triple superphosphate (TSP), respectively. One week later another 50 kg P/ha was added to the soil. The last fertilization was on 22 December, 1984, when an additional 25 kg P/ha and 50 kg K/ha were added. In each fertilization, all fertilizers were applied in solution.

Plants were irrigated frequently with a small amount of deionized water sufficient to keep the soil at field capacity. This precaution was taken to ensure that no drainage from the bottom of the pots occurred. Weeding was done by hand. Greenhouse temperature was maintained at 25-30°C. Additional light, 14 micromoles/m^2/sec, was applied from 1700 until 2130 hours everyday for 60 days because of the short day light period during winter. Light was measured with LICOR Quantum sensor Model 185.

The plants were harvested on 5 January 1985, 60 days after planting. They were cut at the point where the brace roots appeared and chopped to about 12 cm length. Stems were split to aid drying. Plant roots were left in the soil to decompose. Plant fresh weights were recorded before drying at 75°C for 2 days. After drying, plant dry weights were recorded.

Each plant was ground to pass a 2 mm screen in a Wiley mill. Whole plant parts were mixed thoroughly after grinding. A one g sample from each plant was ashed for nutrient analysis. The same procedure for nutrient analysis in the crop residues as described earlier was followed. Only N, P, K, Ca and Mg in the plant tissues were analyzed.

Approximately 50 g of soil were taken from each pot at harvest. The sampling holes were refilled with the same amount of Mulat sand soil. Sampling points were marked with label sticks to ensure that sampling would not occur in the same spot next time. Samples were analyzed for 1 M KCl exchangeable Al, Mehlich I extractable nutrients (P, K, Ca, Mg, Fe, Cu and Zn) and pH (1:2 soil to solution ratio) in water and 1 M KCl solution. Soil organic C and total N were analyzed by Walkley-Black (Allison, 1965) and semimicro Kjeldahl (Bremner, 1965) methods, respectively.

Statistical analysis was conducted using the general linear model (GLM) procedures in the Statistical Analysis System (SAS) according to Barr et al. (1979). Single degree of freedom linear orthogonal contrasts were used to compare treatment means for the levels of residue and N (Chew, 1976). The Duncan's multiple range test (DMRT) was used to compare treatment means for residue types. Data processing was done by an IBM computer at the Northeast Regional Data Center (NERDC) on the University of Florida campus, Gainesville, Florida. Block chart diagrams, three dimensional graphic diagrams and histograms were also computer drawn. Statistical analysis system graphic procedures were followed (Council and Helwig, 1981).

Crop 2

Corn seeds, cultivar 'Pioneer Brand 3059' were planted for the second crop in the same pots as the first crop on 12 January, 1985. No additional residue was added in the second crop. The plants were thinned from 4 to 1 plant/pot one week after planting. On 19 January, 1985, 50 kg P/ha and

75 kg K/ha as TSP and K_2SO_4 respectively were applied in solution.

A second fertilizer application with 50 kg P/ha and 75 kg K/ha were applied on 26 February, 1985. It was observed that all plants showed Mg deficiency symptoms on this date. The older leaves had yellow streakings in between the veins. Magnesium was applied at 50 mg/kg soil as Mg SO_4 to correct the deficiency.

Plant maintainance practices including water supply, greenhouse temperature, light intensity and weeding throughout the growing period of Crop 2 were the same as in Crop 1. The second crop was harvested on 13 March, 1985 (60 days after planting). Data collection on plant and soil samples were recorded the same as in Crop 1. Plant roots were again left in the soil to decompose. Soil sampling holes were refilled with the same amount of Mulat sand soil.

Statistical analysis of the data collected in Crop 2 was conducted in the same way as the data analysis in Crop 1. Soil organic C and total N were not analyzed in Crop 2.

Crop 3

Pregerminated corn seedlings were planted on 13 March, 1985. Again, no residue was added to the soil. On 24 March 24, 1985, 50 kg P/ha and 75 kg K/ha were applied. An additional amount of 50 kg P/ha was given on 4 April, 1985. One week later, 75 kg K/ha was applied. Another 25 kg N/ha were supplied on 19 April, 1985. Three days later, 25 kg Mg/ha was added. Water supply and greenhouse temperature maintenance in Crop 3 were the same as in Crop 1 and Crop 2. Additional light was not supplied in Crop 3 because of sufficient daylength and photoperiod during the spring growth period.

Plants were harvested on 17 May, 1985 60 days after planting. Fresh and dry weights were recorded. The same soil chemical analyses as in Crop 1 and Crop 2 was performed. Soil bulk density data were determined by collecting soil core samples. A small soil core sampler with a ring size 2.7 cm inside diameter and 2.7 cm height was used. The procedure was similar as the method described by Blake (1965) except that the size of core sampler was small.

Plant roots in each pot were separated from soil immediately after harvesting. They were washed with water dried at 70°C for 2 days in a forced air oven. Root dry weights were recorded after the samples were dried.

Soil and plant tissue chemical analysis and data statistical analysis were done in the same way as in Crop 1. In Crop 3, organic C and total N in the soil after harvesting were analyzed.

Results and Discussion

Initial Soil Properties

The results of preliminary analysis of Mulat sand soil are shown in Table 3-1. Particle size distribution consisted of 91% sand, 4% silt and 5% clay. This soil had a low CEC and ECEC which are a typical inherent properties of sandy soils.

The ECEC is defined as the sum of the milliequivalents of Ca, Mg, Al and H in the soil and CEC is only the sum of milliequivalents of Ca, Mg, K and Na in the soil (Kamprath, 1970). The magnitude of CEC was higher than the ECEC because of the adsorption of NH_4^+ ions in the determination of CEC in acid sandy soil by NH_4OAc at pH 7 is pH dependent. The ECEC determination using unbuffered salt solution (1.0 M KCl) was not pH dependent as it extracted only the cations held at active exchange sites at the particular pH of the soil (Tisdale et al., 1985).

Coleman and Thomas (1967) defined acid soils as the soils which has a pH range between 4.0 and 7.0. Mulat sand soil is considered an acid sandy soil as indicated by the pH of 5.7 in water (1:2) and pH of 4.8 in 1 M KCl (1:2).

The difference between pH in 1 M KCl and pH in water (pH) was a net negative charge -0.9. Uehara and Gillman (1991) defined that $\Delta pH = pH_{KCl} - pH_{H_2O}$. The sign and magnitude of pH correspond to the sign and magnitude of

Table 3 Initial properties of Mulat sand.

Particle size distribution :		
sand	91 %	
silt	4 %	
clay	5 %	
pH :		
water (1:2)	5.7	
1M KCl (1:2)	4.8	
C:N Ratio	12 : 1	
Organic matter	3 %	
Total Kjeldahl nitrogen	0.15 %	
CEC, NH_4OAc at pH 7 extraction . (cmol (p^+)/kg)	4.68	
ECEC, 1 M KCl extractant . (c mol (p^+)/kg)	3.34	
Mehlich I [0.05 M HCl + 0.0125 M H_2SO_4] extractable nutrients :		
P	93	mg/kg
K	40	"
Ca	300	"
Mg	32	"
Fe	48	"
Cu	0.35	"
Zn	3.90	"
Soil water retention (dry wt basis)		
1 MPa	8.3 %	
3.33 MPa	7.0 %	
150 MPa	3.1 %	

the surface charge. They also stated that ΔpH of a positive, zero or small negative value (less than -0.5) generally indicates that the soil is dominated by variable charge minerals. If ΔpH in acid soil is near zero, extractable Al content can be expected to be low. A net negative charge is important in soil because cation retention depends on the net negative charge present on the soil colloidal surface (El-Swaify and Sayegh, 1975; Uehara and Gillman, 1981).

According to the guidelines of Rhue and Kidder (1983) regarding the interpretation of Mehlich I extractable nutrients for growing agronomic crops on Florida sandy soils, the amount of P (93 mg/kg) in the Mulat sand was high, K (40 mg/kg) was medium and Mg (32 mg/kg) was high (Table 3-1). There was no current recommendation for the levels of Mehlich I extractable Ca for growing agronomic crops on Florida acid sandy soils. However, 300 mg Ca/kg in Mulat sand soil was considered lower than the average amount of Ca in other Florida soils as reported by Rhue and Sartain (1978). The amount of Cu (0.35 mg/kg) and Zn (3.9 mg/kg) in this soil at pH 5.7 was interpreted to be sufficient and high, respectively (Kidder and Rhue, 1983). Similar to Ca, there is no current interpretation for Mehlich I extractable Fe in Florida acid sandy soils (Dr. E. A. Hanlon personal communication).

Table 3-1 also shows that the water retention of Mulat sand soil was very low. At 3.33 kPa pressure it was 7.1% and at the permanent wilting point (150 kPa) it was 3.1%. As expected, the low water retention capacity of this soil was due to the low clay and organic matter contents. Sandy texture soil has more macropores than micropores in between soil aggregates. Macropores retain less water than micropores. The former characteristically allow the rapid movement of air and percolating water but the latter are mostly filled with water and do not permit much air movement into or out of the soil (Brady, 1984).

X-ray diffractograms of clay fraction (< 2 micron) of Mulat sand are shown in Figure 3-1. Types of minerals present in the sample were 14 Å intergrade, kaolinite, gibbsite and quartz. These minerals are commonly found in highly weathered ultisols (Zelazny and Calhoun, 1971). Judging from the intensity of the diffractograms peaks, minerals quartz, kaolinite and 14 Å intergrade were the major clay minerals present in the sample. Only a small quantity of gibbsite was present.

Kaolinite is a non-expanding 1:1 type of clay mineral. It is usually dominant in a highly weathered soil (Jackson, 1965). Kaolinite was estimated to have a CEC between 3-15 cmol (p+)/kg and a surface area 7-30 m^2/g (Zelazny and Calhoun, 1971). Since Mulat sand soil is made up of 91% sand

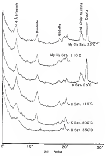


Figure 3-1. X-ray diffraction patterns of the clay fraction (<2 micron) Mulat sand soil, 0-15 cm depth

and it is logical that quartz was a dominant mineral present. Quartz is a tectosilicate and has a hexagonal crystal system (Mackenzie, 1975). The types of minerals present in Hulat sand soil could be one of the reasons the CEC and ECEC of the soil were low.

Plant Residue Composition

Crop residue macronutrient content is presented in Table 3-2. Among the four residue types, corn has a higher ($P = 0.05$) macronutrient content than wheat, oat and rye. The quantity of N, P, K, Ca and Mg in the residues were in agreement with the values reported by Larson et al. (1978), Fenster et al. (1978), and Pathak et al. (1986). Almost twice as much N and P was present in the corn residue as was present in oat, rye and wheat residues. The quantity of these elements in the residues and soil was important in determining the rates of mineralization and/or immobilization of nutrients in the soil (Parr and Papendick, 1978; Blair and Boland, 1978; Reddy et al., 1980).

Micronutrient concentrations of crop residues are presented in Table 3-3. Manganese and Fe concentrations were higher ($P = 0.05$) in corn residue than in the other three residues. It has been reported that soluble Mn and Fe reached potentially toxic levels in normal unsaturated soils when large amounts of plant residue were incorporated

Table 3-2. Macronutrients composition of the crop residues used in the studies

Residue Type	N	P	K	Ca	Mg
			dag/kg		
Corn	1.05 a*	0.20 a	1.08 a	0.51 a	0.32 a
Oats	0.52 d	0.08 c	0.72 b	0.12 c	0.04 d
Rye	0.56 c	0.08 c	0.38 c	0.15 b	0.07 c
Wheat	0.60 b	0.09 b	0.42 c	0.15 b	0.10 b

* Mean values followed by the same letter within column are not significantly different at P=0.05 according to Duncan's multiple range test.

Table 3-3. Micronutrient composition of crop residues.

Residues Type	Mn	Fe	Cu	Zn
		mg/kg		
Corn	2.28 a*	4.85 a	0.03 b	0.33 c
Oats	1.90 b	2.33 c	0.06 a	0.91 a
Rye	0.85 c	2.90 b	0.02 b	0.32 c
Wheat	0.79 c	1.55 d	0.02 b	0.59 b

* Mean values followed by the same letter within column are not significantly different at P=0.05 according to Duncan's multiple range test.

(Elliott and Blaylock, 1975). This study did not show any toxic symptom of Mn and Fe in the soil which could affect plant growth. Levels of Cu and Zn were highest in oat residue.

Effects on Corn Growth and Nutrients Uptake

Crop 1.- Corn growth in Crop 1 was poor. Depending on the treatments, the average plant dry matter weights were only between 7.7 - 9.6 g/plant (Figure 3-2(A)). Applying N increased plant dry weight but the 50 kg N/ha and 100 kg N/ha induced equivalent responses.

Residue type influenced plant dry weights. Corn residue produced the highest plant dry weight and wheat residue the lowest (Figure 3-2(B)). Oat and rye residues were equivalent. Residue type influence on plant dry weight could be attributed to the differential mineralization and nutrient release of the residues. Corn had higher nutrient concentration than other residues.

An analysis of variance (ANOVA) of residue type, N rate, residue rate and their interaction effects on plant dry and fresh weights and tissue nutrient concentration is shown in Appendix Table A-1.

A three dimensional response relationship between the effects of residue rates and N rates on plant dry weight is

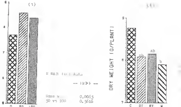


Figure 3-2. Effect of N rate and residue type on corn plant dry weight in Crop 1.

shown in Figure 3-3. Plant dry weight was highest at the highest treatment combination (7.5 mt residue/ha plus 100 kg N/ha). The effect of N rate was significant at P = 0.02 (Appendix Table A-1).

Figure 3-3 suggests that increasing N rates enhanced the nutrient mineralization at the higher residue rates, enabling the crop to take up more nutrients, especially N, P and K. Supporting evidence is shown in Figure 3-4 (B) and Figure 3-5. The uptake of K was increased with increasing residue rate.

Plant dry weights were low in Crop 1 probably because of several reasons. Firstly, only partial decomposition of the residues may have resulted in limited release of nutrients. It was observed that some of these residues were not completely decomposed in the soil at the end of Crop 1. Some of the nutrients such as N and P may have been immobilized to organic forms in the initial stages and not available to the plant. Microorganisms utilized these minerals as energy substrate and competed with growing plants (Doran, 1980; Knapp et al., 1983 a). Secondly, short day length and photoperiod may have had a negative influence on growth. The third reason could be due to the response of corn variety to P level in the soil (Obreza et al., 1982).

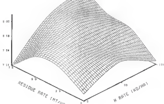


Figure 3-3 Three dimensional relationship [illegible] the effects of residue rate and N rate [illegible] plant dry weight.

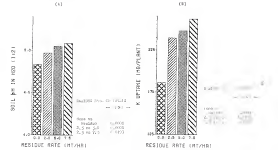


Figure 3-4. Effect of residue rate on soil pH in H_2O and corn plant K uptake in crop 1.

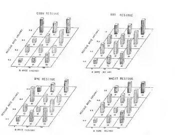


Figure 3-5. Influence of residue rate and N rate on corn tissue P uptake (mg/plant) in Crop 1.

Table 3-4. Single degree of freedom orthogonal contrasts for the mean separation of corn plant P uptake in Crop 1 as influenced by N and residue rate.

N Rate (kg/ha) contrasts	Residue rate (mt/ha)			
	0	2.5	5.0	7.5
	PR>F			
	Corn Residue			
None vs N	0.0854	0.9652	0.0001	0.5527
50 vs 100	0.0992	0.8362	0.0022	0.1460
	Oat Residue			
None vs N	0.0937	0.6477	0.3782	0.3602
50 vs 100	0.1952	0.4168	0.3850	0.1435
	Rye Residue			
None vs N	0.0604	0.6011	0.0591	0.4565
50 vs 100	0.3136	0.1210	0.9356	0.6609
	Wheat Residue			
None vs N	0.5211	0.9278	0.4491	0.0688
50 vs 100	0.1454	0.1625	0.3493	0.9659

An analysis of variance of the effects of treatments and their interactions on corn plant tissue nutrient uptake is shown in Appendix Table A-2. Plant uptake was calculated by multiplying the concentration of the elements in the tissue with plant dry weight. Increasing N rates increased the tissue N and P concentration (Table 3-5). Potassium, Ca and Mg concentrations were not influenced by N application.

Tissue N concentration was not increased by residue rate or type (Tables 3-6 and 3-7). Only K uptake was increased by the residue rates (Figure 3-4[B]). Residue type influenced only the amount of P in the tissue. Corn and oats residues induced higher levels of P in the tissue than rye and wheat. Tissue Ca and Mg concentrations were not affected by the treatments (Appendix Table A-1) although their amount in the soil was increased by the rate of residue applied (Figure 3-11[A] and 3-12[A]). Based on the article by Jones, (1967) tissue N (Table 3-5) was low for treatments 0 and 50 kg N/ha, but it was sufficient at 100 kg N/ha. Tissue P was low but K, Ca and Mg were sufficient.

Plant P uptake (mg/plant) was affected by residue type, residue rate, and N rate as indicated by the strong interaction between these factors in the ANOVA table (Appendix Table A-2). Phosphorus uptake (mg/plant) and single degree of freedom contrasts for N rates are shown in Figure 3-5 and Table 3-4, respectively.

Table 3-5. Effect of applied N rate on corn tissue nutrient concentration in Crop 1

N Rates	N	P	K	Ca	Mg
(kg/ha)			dag/kg		
0	2.50	0.18	2.05	0.38	0.26
50	2.75	0.19	1.87	0.37	0.26
100	2.98	0.22	1.94	0.36	0.29
N Rates Contrasts			PR>F		
None vs N	0.0132	0.0199	0.0879	0.5591	0.3540
50 vs 100	0.0214	0.0001	0.4842	0.8879	0.1180

Table 3-6. Effect of residue rate on corn tissue nutrient concentration in Crop 1.

Residue Rate	N	P	K	Ca	Mg
(mt/ha)			dag/kg		
0	2.48	0.18	1.72	0.39	0.27
2.5	2.52	0.19	1.92	0.39	0.30
5.0	2.58	0.20	1.98	0.36	0.26
7.5	2.59	0.23	2.19	0.34	0.25
Residue Rates Contrasts			PR>F		
None vs Residue	0.2632	0.0322	0.0013	0.3587	0.8361
2.5 vs 7.5	0.5831	0.0355	0.0203	0.4734	0.8139
2.5 vs 5.0	0.6035	0.1242	0.6209	0.5443	0.1455

Table 3-7. Effects of residue type on corn tissue nutrient concentration in Crop 1.

Residue Type	N	P	K	Ca	Mg
			dag/kg		
Corn	2.54 a*	0.22 a	1.97 a	0.36 a	0.28 a
Oats	2.50 a	0.21 a	1.97 a	0.41 a	0.27 a
Rye	2.52 a	0.20 ab	1.96 a	0.38 a	0.26 a
Wheat	2.45 a	0.18 b	1.92 a	0.34 a	0.26 a

* Mean values in the same column followed by the same letter are not significantly different at P= 0.05 according to Duncan's multiple range test.

When corn residue was applied at 2.5 mt/ha, P uptake was increased by increasing N rates. At other residue rates the N rate did not influence the response. Plant P uptake from the oat, rye and wheat residues was not influenced by the N rate applied (Table 3-4). Calcium and Mg uptake were not influenced by the treatments (Appendix Table A-2).

Crop 2.-- The average plant dry weights in Crop 2 were higher than in Crop 1. The range was between 10.4 and 11.9 g/plant for treatments 0 to 100 kg N/ha (Figure 3-6[A]). An analysis of variance of the treatment effects and their interactions showed that plant dry weight in Crop 2 was influenced ($P=0.05$) by the N rate, and the other treatment effects were not relevant (Appendix Table A-4).

Plant dry weights were increased when N rates were increased, especially at the low residue rate (Figure 3-7). Without addition of N (0 kg/ha), the effect of residue rate on plant dry weights was variable. At 2.5 and 7.5 mt/ha residue rate plant dry weights were reduced. More N may be required to satisfy the C:N ratio (C:N ratio < 20) to allow N mineralization to occur.

Crop 3.-- Plant dry weight in Crop 3 was influenced ($P=0.05$) by residue type, residue rate and N rate. An analysis of variance of plant dry weight indicated a triple order

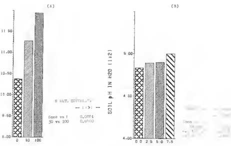


Figure 3-6. Effect of N and residue rates on corn plant dry weight and soil pH in H_2O, respectively at the end of Crop 2.

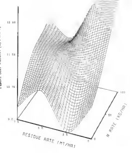


Figure 3-7. Three dimensional relationship between the effects of residue and N rates on corn plant dry weight in Crop 2.

interaction (Appendix Table A-5). Average plant dry weights in Crop 3 were between 15.0 and 20.0 g/plant (Figure 3-8). With the corn residue treatment, the highest plant dry weight was obtained in response to the treatment combination of 5.0 mt residue/ha and 100 kg N/ha. At a higher rate of corn residue (7.5 mt/ha) plant dry weight was reduced.

Oat residue applied at 2.5 mt/ha in combination with 100 kg N/ha produced the highest plant dry weight. For the rye residue treatment, the highest plant dry weight was obtained from a treatment combination 2.5 mt residue/ha plus 50 kg N/ ha. Wheat residue added at 2.5 mt/ha plus 50 or 100 kg N/ha produced about the same plant dry weight (Figure 3-8).

In general, it was observed that N applied at 100 kg/ha in combination with 5.0 mt corn residue/ha increased plant dry weight but with other residues (oat, rye and wheat) the same amount of N was sufficient in combination with 2.5 mt residue/ha to induce a positive response in dry weight.

A larger amount of inorganic N would be required to reduce the C:N ratio of the oat, rye and wheat residues to less than 20:1 than for the corn residue. The C:N ratios for corn, oat, rye and wheat residues were 38:1, 77:1, 75:1 and 80:1 respectively. A C:N ratio of less than 20:1 is required for the mineralization of N in crop residues (Tisdale et al., 1985; Broadbent, 1957).

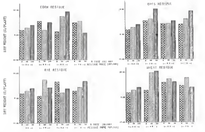


Figure 3-8. Effect of residue type, residue rate and N rate on corn plant dry weight in Crop 3.

Table 3-8. Significant levels for single degree of freedom linear contrasts for the comparison of the mean values of corn plant dry weight in Crop 3 as influenced by N and residue rate.

N rate (kg/ha) Contrasts	Residue rate (mt/ha)			
	0	2.5	5.0	7.5
	PR>F			
	Corn Residue			
None vs N	0.8847	0.4221	0.0308	0.4822
50 vs 100	0.6071	0.2907	0.5357	0.1374
	Oats Residue			
None vs N	0.8847	0.0381	0.8167	0.2270
50 vs 100	0.6071	0.0210	0.6860	0.3662
	Rye Residue			
None vs N	0.8847	0.0452	0.6964	0.2749
50 vs 100	0.6071	0.4480	0.4528	0.9986
	Wheat Residue			
None vs N	0.8847	0.0259	0.7661	0.6102
50 vs 100	0.6071	0.8370	0.6781	0.1904

These results suggest that optimum growth of corn treated with 5.0 mt/ha of corn residue can be obtained with the combination of 100 kg N/ha. Whereas with oat, rye and wheat residues, 100 kg N/ha was sufficient for mineralization of only 2.5 mt/ha of these residues. More than 100 kg N/ha is required for optimum growth if the amount of oats, rye and wheat residues added was 5.0 mt/ha or more. Immobilization of N may have taken place when high rates of residue were applied especially when the C:N ratios were high. Similar results were reported by Pinck et al. (1950), Hendrickson (1985), and White (1984).

The effects of treatments and their interactions on root dry weight and shoot:root ratio are shown in Appendix Table A-5. Root dry weight was influenced by residue type. Application of oat residue induced the highest root dry weight and wheat residue the lowest (Figure 3-9[A]). Shoot:root ratio was also affected by residue type (Appendix Table A-5). It was highest with the wheat residue treatment and lowest with corn residue treatment (Figure 3-9[B]). An explanation for the differential response in root dry weights and shoot:root ratios could be related to the nutrient release pattern of the residues. Boote (1977) reported that the plant shoot:root ratio was dependent upon the availability of nutrients in the soil. A similar hypothesis was proposed by Barber (1984). Plant root weights

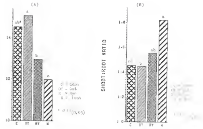


Figure 3-9. Effect of residue type on corn root dry weight and shoot:root ratio in Crop 3.

were recorded only in Crop 3. In Crop 1 and Crop 2 the roots were left in the soil to decompose.

Effects on Soil Properties

Crop 1.-- An analysis of variance of the effect of treatments and their interactions on soil pH and Mehlich I extractable nutrients is presented in Appendix Table A-3. Soil pH in water and 1 M KCl were affected by residue types and rates. Soil pH in H_2O 1:2 (soil:solution ratio) was increased when residue application was increased (Figure 3-4(A)). This increase in pH could be due to the removal or complexation of exchangeable Al by the organic matter (Figure 3-10). Addition of crop residues reduced the amount 1 M KCl exchangeable Al. Furthermore, where no residue was applied, increasing the N rate reduced the amount of exchangeable Al in soil. This could possibly be due to the enhancement effect of N on the decomposition of organic matter (3%) in soil. Single degree of freedom linear contrasts for N rates are shown in Table 3-9. In general, application of N in combination with crop residue did not increase the 1 M KCl exchangeable soil Al in soil. The effectiveness of organic matter in removing exchangeable Al from soil solution has been observed by other researchers (Hargrove and Thomas, 1981; Pionke and Corey, 1967; Ahmad and Tan, 1986).

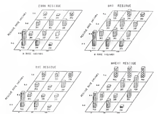


Figure 3-10. Effect of residue rate and N rate on 1 MKCl exchangeable Al (mg/kg) in soil at the end of Crop 1

Table 3-9. Significant levels for single degree of freedom linear contrasts for the comparison of the mean values of 1N KCl exchangeable Al in the soil at the end of Crop 1 as influenced by N and residue rate.

N Rate (kg/ha) contrasts	Residue rate (mt/ha)			
	0	2.5	5.0	7.5
	PR>F			
	Corn Residue			
None vs N	0.0017	0.5219	0.2015	0.8013
50 vs 100	0.1227	0.6318	0.6932	0.3285
	Oat Residue			
None vs N	0.0255	0.8027	1.0000	0.8922
50 vs 100	0.6583	0.2237	0.0134	0.0697
	Rye Residue			
None vs N	0.0015	0.5101	0.8655	0.7502
50 vs 100	0.0485	0.8682	0.0037	1.0000
	Wheat Residue			
None vs N	0.0005	0.7875	0.0246	0.8443
50 vs 100	0.0023	0.2761	0.3417	0.9096

Residue type influenced soil pH (Appendix Table 3-3). Soils receiving wheat, oat and corn residues had a higher pH in water (1:2) than soils receiving rye residue (Table 3-10). The highest water and 1 M KCl pH were obtained in soil treated with corn residue and the lowest in soils treated with rye residue. The magnitude of differences might not practically meaningful although it was significantly different at P = 0.05 level.

Another possible reason for the soil pH increase in response to the addition of crop residues (Table 3-10) is the removal of H^+ from soil solution by the negative charge of Al oxides or Si oxides (Dr. T. L. Yuan, personal communication). Decomposition of organic residues could result in formation of CO_2 which combines with water to form carbonic acid. Dissociation of this weak acid into H^+ and HCO_3^- would thus provide H^+. But H^+ could be attached to the negative charge of an O_2 atom on the surface of Al or Si oxides present in this acid soil. This series of possible reactions is illustrated as follows:

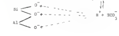


Table 3-10. Effect of residue type on soil pH and Mehlich I extractable soil nutrients at the end of Crop 1.

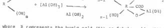
Residue type	Soil pH (1:2)		Mehlich I extractable						
	H_2O	1 M KCl	P	K	Ca	Mg	Fe	Cu	Zn
			mg/kg						
Corn	4.99a*	4.48a	163a	18a	184a	36ab	48a	0.14b	3.68a
Oats	5.00a	4.46b	175a	18a	179a	38a	51a	0.17a	2.95a
Rye	4.95b	4.44c	166a	19a	170a	32b	49a	0.14b	3.38a
Wheat	5.00a	4.45bc	173a	18a	182a	39a	49a	0.14b	3.42a

* Mean values in the same column followed by the same letter are not significantly different according to Duncan's multiple range test (P=0.05).

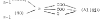
Lindsay (1979) stated that in aqueous solutions of Al^{3+} is surrounded by six molecules of water in the form of Al$(H_2O)_6^{3+}$. This form can be hydrolized when the pH increases. Protons are removed from the coordinated water giving a series of hydrolysis products:

$$\begin{aligned}
Al(H_2O)_6^{3+} &\rightleftharpoons Al(H_2O)_5\ (OH)^{2+} + H^+\\
&\rightleftharpoons Al(H_2O)_4\ (OH)_2^{+} + 2H^+\\
&\rightleftharpoons Al(H_2O)_3\ (OH)_3^{0} + 3H^+\\
&\rightleftharpoons Al(H_2O)_2\ (OH)_4^{-} + 4H^+\\
&\rightleftharpoons Al(H_2O)\ (OH)_5^{2-} + 5H^+
\end{aligned}$$

In the presence of organic matter, humic materials can react with Al hydroxides to form a complex as proposed by Levashkevich (1966). The proposed reaction is as follows:



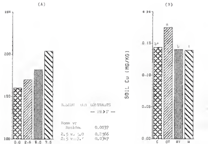
where R represents the humic acid (HA) or fulvic acid (FA) nucleus and OH is a phenolic hydroxyl group. He also suggested that Al hydroxide can interact with HA or FA to form a hydrated complex as follows:



[illegible] shown in Figure 3-10 might be related to the Al-organic matter complex mentioned by Levashkevich (1966). It was beyond the scope of this study to evaluate this complex. An analysis of variance of the 1 M KCl exchangeable soil Al indicated that residue type, residue rate and their interactions were highly significant (P=0.01, except for residue rate P=0.05) (Appendix Table A-3).

Mehlich 1 extractable P, K, Fe and Zn were not influenced by the treatments (Appendix Table A-3). Soil Ca increased with increasing residue application (Figure 3-11(A)). However, the mean difference between residue rates 2.5 and 5.0 mt/ha was not significant. The amount of Ca released by the residue was calculated by subtracting the Ca concentration of the control from the Ca in 7.5 mt residue/ha treatment. Approximately 5 mg Ca/kg soil was released from each mt of residue applied. This quantity is considered as 'apparent mineralizable' Ca in the residue.

Although the quantity of Ca in soil was affected by the residue rate, the amount taken up by the corn plant was not (Compare Appendix Table A-2 and Appendix Table A-3). Calcium levels in the residues were high especially in corn (Table 3-2). Calcium could be released from soil minerals by a weathering process in which organic acids produced by the residues during decomposition degraded the soil minerals (Tan, 1986). Therefore, the 'actual' amount of Ca



RESIDUE RATE CONTRASTS

— PR > F —

None vs Residue	0.0037
2.5 vs 5.0	0.2566
2.5 vs 7.5	0.0347

Figure 3-1. Effect of residue rate and residue type on Mehlich I extractable Ca and Cu in soil at the end of Crop 1.

mineralized from the residues cannot be precisely determined.

Tissue Ca was not affected by applied treatments. Soil Ca could be held strongly by the humic fraction of the organic matter to form Ca-humate (Bloom, 1981). Calcium is taken up by the plant only in the ionic form Ca^{2+} (Barber, 1984).

Mehlich I soil extractable Cu was higher in oat residue ($P=0.05$) than in the other three types of residue (Figure 3-11(B)). Corn, rye and wheat residue treatments contained about the same quantities of Cu. The effect of residue type on Mehlich I soil extractable Cu corresponded to the original amount of Cu in the residues (Compare Figure 3-11(B) with Table 3-3). Residue and N rates did not influence the amount of Mehlich I soil extractable Cu (Appendix Table A-3).

Copper may be bound with the organic matter to form a complex. Bloom (1981) suggested that the Cu^{2+} ion is possibly bound by coordinate bonds to water and carboxyl O_2 of the organic matter to form an inner sphere complex formation. Such complex formation restricts the mobility of Cu^{2+} ion in the soil. Electron spin resonance spectroscopy (ESR) of this complex formation showed that it was not necessarily indicative of chelate formation (dc Bride, 1978).

Mehlich I soil extractable Mg at the end of Crop I was affected by residue rate, residue type and N rate (Appendix Table A-3). Plant residue application increased the amount of Mg in the soil. However, soil Mg did not vary between 2.5 and 5.0 mt/ha of residue added (Figure 3-12[A]). The highest amount of Mg was found in treatments receiving 7.5 mt residue/ha (42 mg Mg/kg soil) and the lowest in the control (32 mg Mg/kg soil). Calculated average Mg release/mt of residue is about 1.3 mg Mg/kg.

Oat and wheat residue treatments had the highest amount of extractable soil Mg and the rye residue treatment the lowest (Figure 3-12[B]). This result did not follow the trend of the original content of this element in the residue (Table 3-2). A possible explanation could be due to the complex formation between the humic fraction of these residues with Mg^{2+}. Fulvic acid (FA) has a greater affinity for Mg^{2+} than other cations (Schnitzer and Hansen, 1970). Different residue types could release different amounts of FA upon decomposition and the higher the amount of FA the more Mg^{2+} that could be bound or complexed.

Schnitzer and Kodama (1977) divided the decomposed products of animal and plant residues into 'humic' and 'nonhumic' substances. The humic fraction is the major portion of the organic matter in soil which is not easily attacked by microorganisms. It has a long survival rate while the

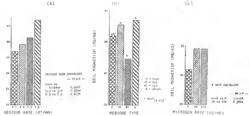


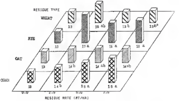
Figure 3.12. Effect of residue rate, residue type and N rate on Mehlich I extractable Mg in soil at the end of Crop 1.

non-humic portion is the opposite. The humic fraction [illegible] divided into 3 categories called humic acid (HA), fulvic acid (FA) and humin based on their solubility in alkali and acid. The humic fraction plays an important role in the formation of stable water soluble complexes with metal ions and hydrous oxides (Schnitzer and Skinner, 1965).

Addition of N increased the amount of Mehlich I extractable soil Mg. However, application of 50 and 100 kg N/ha produced the same effect on soil Mg (Figure 3-12[C]). Addition of N probably enhanced the residue decomposition which subsequently released Mg into the soil. The average increase of soil Mg due to the addition of N compared to the amount in the control (no N) was small, about 3.5 mg Mg/kg soil.

Crop 2.- An analysis of variance of treatment effects and their interactions on soil parameters is presented in Appendix Table A-4. Soil pH values (both in water and 1 M KCl) were affected only by residue rate. Increasing residue rate increased the soil pH (P=0.05) (Figure 3-6[B]). Although the pH increase due to the residue might not be agronomically important it could have a long term effect on soil acidity.

Mehlich I extractable K and Ca were influenced in a non-parallel fashion by the interaction of residue type and rate (Appendix Table A-4). Figure 3-13 shows the amount of



* Mean values in the same column followed by the same letter are not significantly different at P = 0.05 according to Duncan's multiple range test.

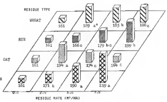
Figure 3-13. Interaction between residue type and residue rate on Mehlich I extractable K (mg/kg) in soil at the end of Crop 2.

soil K at various residue rates and types. Duncan's multiple range test for comparison of mean values of soil K at the residue rate of 2.5 mt/ha showed that the highest quantity of K occurred with rye and the lowest with oat and corn. At 5.0 mt residue/ha, rye and corn produced the highest soil K, wheat the lowest.

Effect of residue type and rate on Mehlich I extractable soil Ca was different from K. Figure 3-14 shows that at 2.5 mt residue/ha, oat and wheat were superior to corn and rye in supplying Ca. Corn residue applied at 5.0 mt/ha resulted in the highest level of soil Ca whereas, oat produced the lowest level. At the highest rate of residue (7.5 mt/ha), corn again produced the highest soil extractable Ca level and oat the lowest.

Data in Figures 3-13 and 3-14 suggest that the Mehlich 1 extractable K and Ca in Mulat sand soil after 6 months incorporation with crop residues were dependent upon the type and rate of residues applied. These data also indicate that at higher residue rates (5.0 and 7.5 mt/ha) corn residue produced the largest amount of soil K and Ca compared to the other three residue types. This was possibly due to the higher degree of humification of crop residues (Compare Appendix Tables A-3 and A-4).

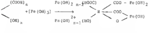
Mehlich I extractable soil Fe was influenced by residue type (Appendix Table A-4). It was higher in corn and rye



* Mean values in a column followed by the same letter are not significantly different at P = 0.05 according to Duncan's multiple range test.

Figure 3-14. Interaction between residue type and residue rate on Mehlich I extractable Ca (mg/kg) in soil at the end of Crop 2

treatments than in the wheat treatment (Table 3-11). The results were different from the trends of original Fe content in the residues. One possible reason for this divergence could be due to the additional Fe produced by the degradation of clay minerals by organic acids from residues and complexation by HA and FA. Different types of residue may have produced different amounts of FA and HA. Levashkevich (1966) suggested that the reaction between FA or HA with Fe hydroxide in acid sandy soil is as follows:



where R represents HA or FA nucleus and OH is a phenolic hydroxyl group. Complexation of Fe with the humic fraction of organic matter rendered the element less available in exchangeable form (Stevenson, 1982).

Mehlich I extractable soil P, Cu and Zn at the end of Crop 2 were not affected by the treatments (Appendix Table A-4). The results were similar to Crop 1 except that soil Cu was affected by the residue type in Crop 1 (Compare Appendix Tables A-3 and A-4).

Table 3-11. Effect of residue type on Mehlich I extractable soil nutrients at the end of corn Crop 2.

Residue Type	Mehlich I extractable						
	P	K	Ca	Mg	Fe	Cu	Zn
	mg/kg						
Corn	105 a*	45 a	195 a	48 a	37 a	0.41 a	1.73 a
Oat	94 a	44 a	183 a	50 a	35 ab	0.41 a	1.84 a
Rye	103 a	45 a	186 a	44 a	36 a	0.41 a	1.65 a
Wheat	105 a	44 a	197 a	48 a	33 b	0.41 a	1.51 a

* Mean values followed by the same letter within column are not significantly different at (P=0.05) according to Duncan's multiple range test.

Crop 3.. The effects of treatments and their interactions on soil pH and Mehlich I extractable soil nutrients are shown in Appendix Table A-6. Residue rate increased soil pH (P=0.01). Residue and N rates interacted in their influence on both water and 1 M KCl soil pH (P=0.05). This relationship of residue and N rate on soil water pH is shown in a surface response diagram (Figure 3-15). The lowest pH (4.78) was observed in the control treatment (no N and no residue) and highest at 7.5 mt residue/ha (pH = 5.07).

A strong relationship between soil pH and 1 M KCl exchangeable soil Al was observed. Soil pH was lowest when the amount of 1 M KCl exchangeable Al was highest and vice versa (Compare Figure 3-15 with Table 3-12). The effectiveness of organic matter in reducing the amount of 1 M KCl exchangeable soil Al has been discussed earlier in Crop 1. Reaction of acidic Al in soil was proposed by Pionke and Corey (1967) as follows:

$$\begin{array}{ccccc} & & \mathrm{Al\ (OH)_3} & & \\ & & \updownarrows & & \\ & & \mathrm{Al_y\,(OH)_{3y-z}^{+z}} & & \\ & & \updownarrows & & \\ & & \mathrm{Al\ (OH)^{2+}} & & \\ & & \updownarrows & & \\ \mathrm{Al - OM} & \rightleftharpoons & \mathrm{Al^{3+}} & \rightleftharpoons & \mathrm{Al - X} \end{array}$$

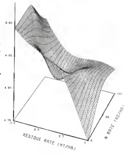


Figure 3-15: Three dimensional relationship between the effects of residue rate and N rate on soil pH in water (1:2) at the end of Crop 3.

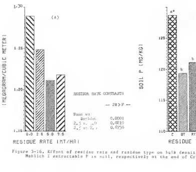
Table 3-12. Effects of N and residue rate on 1M KCl exchangeable soil Al at the end of Crop 3.

N rate	Residue rate (mt/ha) 0	2.5	5.0	7.5
(kg/ha)	(mg/kg)			
0	465	375	350	325
50	385	374	345	320
100	370	360	340	315
N rate Contrasts	PR>F			
None vs N	0.0025	0.9872	0.8352	0.8612
50 vs 100	0.6520	0.8201	0.9341	0.7330

where Al^{3+} represents the activity of hydrated trivalent Al ions on soil solution, Al-x refers to KCl exchangeable Al, Al-OM refers to the component of nonexchangeable acidic Al complex by organic matter, and $Al_y(OH)_{3y-z}^{+z}$ refers to the component of non-exchangeable acidic Al that is polymerized and probably residing on particle surfaces.

Soil bulk density was affected only by the residue rate (Appendix Table A-5). Crop residue addition decreased the bulk density of the soil (Figure 3-16(A)). Single degree of freedom linear contrasts indicated that the mean difference between treatments 2.5 and 5.0 mt residue/ha was significant at 2% level but was not significant at the 5% level for the difference between 2.5 and 7.5 mt residue/ha. Reduction of soil bulk density in response to the addition of varying residue rates has been reported by other researchers (Black, 1973 b; Black and Siddoway, 1979; Morachan et al., 1972). However, some reports have shown that crop residue addition to the soil had no effect on bulk density (Bhatnagar et al., 1983; Hedge et al., 1982; Ketcheson and Beauchamp, 1978).

Mehlich I extractable soil P was influenced only by residue type (Appendix Table A-6). Corn residue treatment produced higher levels of soil P than oat, rye and wheat (Figure 3-16(B)). A reduction in soil P due to residue addition was reported by Black (1973 b); Black and Siddoway



RESIDUE RATE CONTRASTS

	-- PR > F --
None vs Residue	0.0001
2.5 vs 5.0	0.0219
2.5 vs 7.5	0.6736

Figure 3-16. Effect of residue rate and residue type on bulk density and Mehlich I extractable P in soil, respectively at the end of Cro[illegible]

(1979), and Larson et al. (1972). However, in a long term study (20 yr) in Canada, Halstead and Sowden (1968) reported that the effect was not consistent. White (1984) also reported that the effect of residue on soil P was unclear. The contradictory results on the effect of residue on available P might be due to the different types of soil used.

Mehlich I extractable soil Mg and Zn at the end of Crop 3 were influenced by the residue type (Appendix Table A-6). Soil Mg was highest in both corn and wheat residues treatments and lowest in oat residue treatment (Figure 3-17(A)). Soil Zn was higher in the oat residue treatment than the corn, rye and wheat treatments. The three residues (corn, rye and wheat) produced about the same amount of extractable soil Zn. Oat residue originally contained more Zn than the other residues (Table 3-3).

Soil K was increased by increasing levels of N (Figure 3-18(A)). This could be due to release of greater quantities of K as a result of more residue decomposition in response to increasing N rates. A similar result was reported by Black (1973 b) and Halstead and Sowden (1968).

The effect of N on soil Ca was significant at the 5% probability level (Figure 3-18(B)). The reduction of soil Ca could be due to the formation of Ca-humate as a result of more rapid residue decomposition. Calcium-humate is an unavailable form of Ca (Bloom, 1981).

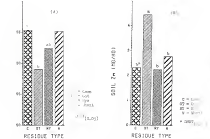


Figure 3-17. Effect of residue types on Mehlich I extractable soil Mg and Zn at the end of Crop 3.

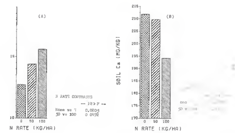


Figure 3-18. Effect of N rate on Mehlich I extractable soil K and Ca at the end of Crop 3.

Residue addition increased the amount of K and Zn in the soil (Table 3-13). Extractable soil K was increased by increasing the rate of residue addition from 2.5 to 7.5 mt residue/ha (P=0.05) but the intermediate level of 5.0 mt/ha was not different from 2.5 m/ha.

Comparisons of the soil C:N ratios were made between Crop 1 and Crop 3 (Table 3-14). Increasing residue rate increased the soil C:N ratio. The C:N ratio of the control treatment (no residue) decreased between Crop 1 and Crop 3. This reduction could be due to the lost of C as CO_2 during soil organic matter decomposition. Residue addition increased the C:N ratios because of the C added from the residues.

Conclusions

Crop residues contributed to the overall fertility of Mulat sand soil. However, the treatment effects varied between Crop 1, Crop 2 and Crop 3 possibly due to the residue decomposition and nutrient mineralization. Plant dry matter production for the three crops followed this trend: Crop 3 > Crop 2 > Crop 1.

A strong relationship was observed between soil pH and 1 M KCl exchangeable soil Al. Crop residue addition reduced the exchangeable soil Al and increased soil pH in all three crops.

Table 3-13. Effect of residue rate on Mehlich I extractable soil nutrients at the end of Crop 3.

Residue rate	Mehlich I extractable						
	P	K	Ca	Mg	Fe	Cu	Zn
(mt/ha)	mg/kg						
0	124	13	198	60	40	0.11	2.47
2.5	123	14	205	64	41	0.10	2.56
5.0	122	16	206	64	42	0.10	3.10
7.5	120	18	212	64	43	0.10	3.61
Residue rate Contraste	PR>F						
None vs Residue	0.6921	0.0417	0.1419	0.0620	0.4670	0.1659	0.0351
2.5 vs 7.5	0.8608	0.0357	0.9095	0.9801	0.5432	0.9506	0.2206
2.5 vs 5.0	0.5536	0.3327	0.3384	0.9880	0.8791	0.8956	0.8661

Table 3-14. Soil C:N ratios in Crop 1 and Crop 3 as affected by the residue rate.

Residue rate (mt/ha)	C:N ratio		
	Crop 1	Crop 3	Difference
0	11.6	11.5	-0.1
2.5	11.7	13.2	1.5
5.0	12.0	13.7	1.7
7.5	12.2	14.1	1.9
LSD (0.05)	0.2	0.5	0.1

Mehlich I extractable nutrients in soil increased due to residue contents of the studied elements. Uptake of N, P and K by corn in Crop 1 was affected by the residue treatments, but Ca and Mg were not. The release of Ca and Mg in soil possibly formed a complex with soil organic matter which is not plant available.

Tissue N was increased by N addition but was not affected by residue type and rate. Levels of tissue P depended on residue rate, and type and N rate. Potassium uptake increased with increasing residue rates.

Nitrogen must be added to grass-straw residues to satisfy the C:N ratio for mineralization of nutrients. The addition of 50 kg N/ha was sufficient for corn residue mineralization. However, oat, rye and wheat residues require more than 100 kg N/ha to induce positive response on corn growth. With this in mind, farmers should choose residues which have low C:N ratios. Corn always is a better choice than oat, rye and wheat. Residue type not only influenced plant dry weight but also root dry weight. Response to application of a given residue is apparently related to the amount of nutrients released by the residue.

Corn growth was reduced when the crop was planted immediately after incorporation of residue. Planting the crop 60 days after incorporation of residues was beneficial for corn growth. Therefore it is recommended that the soil after incorporation with residue should be left fallow for at least 2 months before planting the following crop. However, further research needs to be carried out under field conditions to verify this recommendation.

Soil bulk density was reduced and soil C:N ratio was increased by the addition of residues. A reduction in bulk density should result in a greater porosity and better soil structure and aggregation.

The following points should be considered in future studies on crop residue addition into soil:

(a) Use a low fertility soil so the effects are more pronounced. Mulat sand would be classified as a moderately fertile soil because of its levels of nutrients and organic matter.

(b) Use crop residues which are relevant to the cropping system such as corn, peanut (*Arachis hypogae* L.), soybean (*Glycine max* L.) and vetch (*Vicia villosa*). These crops are usually planted in the cropping system in a tropical and subtropical area like Florida.

(c) Methods of residue addition into soil should be evaluated, i.e. residue cut and left on soil surface, burning, and residue left standing without cutting.

(d) Allowing 60 days for the residue to decompose before planting the next crop may not be practical. Therefore, solutions to this problem are worth investigating.

(g) Be careful in attempting to apply greenhouse results to field application because the environmental variability in the field is usually difficult to control.

CHAPTER IV

LABORATORY INCUBATION STUDIES OF CROP RESIDUE TYPES AND APPLICATION RATES WITH AND WITHOUT N ADDITION.

Introduction

For many yr, exogenous sources of organic materials have been used as supplements to cover crops in an attempt to maintain the soil organic matter. Many studies have evaluated the effects of crop residue additions on plant growth and, to a lesser extent, on soil properties (Bhatnagar et al., 1983; Black, 1973 b; Douglas et al., 1980; Karlen et al., 1984). In contrast, with the exception of the notable works by Bond and Willis (1969), Broadbent and Bartholomew (1949), and Hallam and Bartholomew (1953), little attention has been given to characterizing the decomposition of various types and application rates of crop residues.

Full scale field testing, even in small plots, however requires time and effort, and is subject to variability induced by weather and management. Such effort and variability could be reduced if laboratory incubation of crop residues mixed with soil could serve as a valid screening for decomposition rates. Such a test might also provide more information on the course of decomposition than is possible to obtain under field conditions.

Crop residue decomposition rates can be estimated by 1) measuring the CO_2 evolution, 2) measuring O_2 uptake, 3) determining weight loss and 4) estimating the disappearance of a specific constituent such as cellulose and lignin (Alexander, 1977; Reddy et al., 1980). In this study the first method was chosen because it is the most common and accurate method available.

Accordingly three laboratory incubation studies were designed to examine the decomposition of crop residues in the same soil used in the glasshouse studies (Chapter III). The studies were: 1) The effects of residue type on CO_2 evolution at a fixed rate of residue (5.0 mt/ha) without addition of N, 2) The effects of 4 residue rates and 4 residue types on CO_2 evolution without addition of N and 3) The effects of 3 N fertilizer rates on CO_2 evolution at a fixed rate of residue (5.0 mt/ha).

The objective of the first study was to compare the decomposition rate of corn, oat, rye and wheat residues at 5.0 mt/ha without added N. The 5.0 mt/ha rate was chosen to represent a medium rate of residue addition. The second study was aimed to compare the effects of four loading rates (0, 2.5, 5.0 and 7.5 mt residues/ha) without addition of N. The third study was to compare the effects of 3 N rates (0, 50, and 100 kg/ha) on the decomposition of 4 residue types at 5.0 mt/ha. In all studies the residue decomposition rates were determined by the amount of CO_2 or CO_2-C evolved from the mixtures of residues and soil or so called 'soil respirometer'.

Materials and Methods

One hundred g of air dry Mulat sand soil plus 250 mg of crop residue were mixed with 100 g soil in 500 mL Erlenmeyer flasks which gave equivalent amount of 5.0 mt residue/ha. The soil was taken from the bulk soil samples for glasshouse studies (Chapter III). Mixtures were moistened to approximately field capacity (7% by weight basis) by adding CO_2-free water. Controls were prepared identically but without crop residue addition. Each treatment including controls was replicated 3 times. Crop residues used was between 0.5 and 1.0 cm length.

A stream of humidified CO_2-free air was passed through the flasks and the evolved CO_2 from each flask was collected in test tubes containing 50 mL 0.1 M NaOH solution (Figure 4-1). The air stream passed into the flasks from an aquarium pump was purified in a scrubber system in a series of three 1000 mL flasks. The flasks, in series, contained concentrated H_2SO_4, 3 M NaOH solution and CO_2-free water. The concentrated H SO was used to remove short chain C compounds in the air. Three M NaOH were used to remove CO_2 in the air. Between the scrubber and each incubation flasks

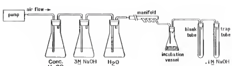


Figure 4-1 Schematic of laboratory incubation apparatus showing incubation vessel and one of the CO_2 traps. All flasks received CO_2-free air from one manifold.

was a manifold which distributed the air into the flasks through equal length capillary tubes, thus providing an equal flow rate for each flask. A control valve was used to regulate or adjust air flow. Air flow rate was about 20 mL per minute of CO_2-free air. The rate was adequate for a similar incubation study (Stotzky, 1965).

The 50 mL of 0.1 M NaOH solutions were replaced at 1, 2, 4, 7, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55 and 60 days from the day experiment was started. Each of these samples were titrated with 0.1 M HCl following precipitation of CO_2 with 1.5 M $BaCl_2$ solution to a phenolphtalein end-point (Stotzky, 1965). The amount of CO_2 evolved was determined by the following equation:

$$(B - V)\ \underline{M}\ E = \text{mg}\ CO_2$$

where:

B = average volume of HCl required to titrate the NaOH from the blank treatment.

V = volume required to titrate the NaOH solution from the specific treatment.

M = the molarity of HCl, (0.1 M).

E = equivalent weight of CO_2.

A similar technique was followed in all incubation studies. Different treatments were imposed to suit the objective in each study. In the study to compare the effects of three N rates on the decomposition rate of crop residues at 5.0 mt/ha, the N was applied in solution form. Ammonium nitrate dissolved in CO_2-free water was used as the inorganic N source.

Room temperature was maintained at 25 ± 2°C during each experimental period. Flasks containing soil-crop residue mixtures were weighed periodically adjusted to ensure that the soil water content was adequate.

Statistical analysis of the differences in CO2 evolution among the treatments was carried out using the non-linear model procedures in SAS (SAS Institute Inc., 1985). Since each experiment was conducted once within 60 days of incubation the best non-linear regression equation to fit the amount of cumulative CO_2 is $\hat{Y} = A\,x^{\frac{1}{2}}$ where Y is the estimated value of cumulative CO_2, A is a constant and depends on the residue type and x is the time of incubation (days). This regression model was adapted from Little and Hills (1978). If the incubations are carried out for a very long time the best model to fit is $\hat{Y} = A\,(1 - e^{-kx})$ where $\hat{Y}$ is the estimated value of cumulative CO_2, A is a constant which depends on the residue type, K is a decomposition rate constant and x is the time of incubation (days).

Comparisons were made among the residue treatments using the Duncan's multiple range test. A least significance difference (LSD) procedure was used to compare the mean values of CO_2 evolved by different residue rates and N rates at the 5% probability level when the treatment effects were significant. Calculations were done using the IBM computer at the Northeast Regional Data Center (NERDC) located on the University of Florida campus. Diagrams were computer drawn by using SAS/Graph user's guide (Council and Helwig, 1981).

Results and Discussions

CO_2 Evolution of Soil-Residue Type.

Mean cumulative CO_2 evolution varied considerably among residue types (Figure 4-2). The trend of cumulative CO_2 evolved during the first 32 days of incubation was oat > corn > rye > wheat > control treatment. However, in between 32 to 60 days the corn residue plus soil mixture evolved a larger quantity of CO_2 and the trend was changed to corn > oats > rye > wheat > control. The larger amount of CO_2 evolved from the oat treatment during the first 32 days as compared to corn treatment could be due to the higher fraction of readily available C in oat residue. It has been observed by Knapp et al. (1983 b) that the higher the fraction of available C in the residue, the greater the amount of CO_2 evolved or higher the decomposition rate. Total C in the residue was not a good parameter to estimate the relationship between C:N ratios and residue decomposition rate. However, in this study it was found that the total CO_2-C or CO_2 evolved from residue plus soil

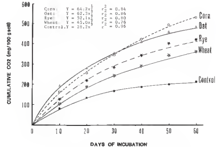


Figure 4-2. Effect of residue type on the cumulative amount of CO_2 evolved during 60 days of incubation. The application rate for each type of residues was 5.0 mt/ha.

mixtures was a good estimator of residue decomposition rate (Table 4-2 and Figure 3-2).

Addition of a weak acid was found to inhibit CO_2 evolution (Hendrickson, 1985). Therefore, corn residue may have produced more organic acids than oat residue and less CO_2 was evolved in the first 32 days of incubation. After 32 days, microbes may possibly utilize the organic acids as an energy substrate and the organic acids were not a factor that reduced the CO_2 evolution.

Another possible reason for the smaller quantity of CO_2 evolution by corn residue treatment could be due to its high lignin content. Lynch (1979) reported that the lignin content in mature corn residue was higher than in mature oat residue. But, cellulose and hemicellulose contents were opposite. Lignin was found to be more resistant to decomposition than other types of compounds such as cellulose and hemicellulose (Alexander, 1977; Kononova, 1961; Pathak et al., 1986; Waksman and Gerretsen, 1931).

The greatest amount of CO_2 evolved in every treatment was during the first 10 days of incubation (Table 4-1). The exception being only in the corn residue treatment where a large amount of CO_2 was evolved for up to 20 days. The respective percentages of CO_2 evolved during the first 10 days of incubation from corn, oat, rye and wheat residues treatments were 23.5, 39.6, 31.1 and 30.8%. These values

Table 4-1. Total amounts of CO_2 evolved by four residue plus soil mixture and control treatment at every 10 days interval during 60 days of incubation.

Incubation Interval	Control (No residue)	Residue Type			
		Corn	Oat	Rye	Wheat
(days)	(mg CO_2 per 100g soil)				
0-10	80 d*	153 b	192 a	146 b	124 c
11-20	50 d	103 a	84 b	71 c	65 c
21-30	35 e	94 a	76 b	66 c	55 d
31-40	20 d	74 a	58 bc	63 b	49 c
41-50	15 d	66 a	55 b	56 b	45 c
51-60	10 c	30 a	28 a	20 b	15 c
Total	210 e	520 a	493 b	422 c	353 d

* Mean values within row followed by the same letter are not significantly different at P = 0.05 according to Duncan's multiple range test.

were obtained by subtracting the control from cumulative amounts of CO_2 in each residue treatments after 10 days of incubation and dividing by the cumulative amount of CO_2 in the same treatments minus control at 60 days incubation and multiplying by 100.

In general, the amount of CO_2 evolved per day in every treatment decreased with time. This implies that the rate of residue decomposition decreased with time. Many researchers reported that the rate of decay of organic matter (including plant residues) in soil was exponentially decreased with time and followed the first order kinetics (Lynch, 1979; Reddy et al., 1980).

Reddy et al. (1980) also reported that the decomposition of plant residues and animal wastes had two and three phases. This can be seen in the data presented in Table 4-1, where Phase I was between 1-10 days and Phase II was after 10 days incubation. Curvilinear regression equations for the different residue treatments are shown in Figure 4-2. A large coefficient for x implies a high CO_2 evolution rate. In general, the coefficients for the curvilinear relationships for residue treatments was in the order of corn > oat > rye > wheat > control.

Instead of using the values of CO_2, the amounts of CO_2-C were calculated and were used to estimate the amount of C loss in each treatment. The amount of C loss was assumed to be proportional to the rate of decay of the materials. The conversion of CO_2 to CO_2-C was calculated by multiplying the values of CO_2 by 0.27 which is the ratio of C in CO_2. The actual amount of C in the soil and in the plant residues were determined earlier (Chapter III). Carbon loss from each treatment was measured by the amount of CO_2-C evolved. These data are presented in Table 4-2. It was noted that the percentage of CO_2-C evolved from corn, oat, rye and wheat residue treatments were 84.8, 77.0, 55.1 and 32.5%, respectively. These values represent the actual percentage of C or organic material decomposed during 60 days under the same temperature and moisture conditions and same soil type. The trend of decomposition was corn > oat > rye > wheat > control. The percentage of CO_2-C released from the control (no residue) treatment was only 3.3%. It seemed that most of the C in the control treatment was unavailable C and resistant to degradation.

Comparisons between the control and residue-treated treatments showed that the residue treatments decomposed about 10-26 times faster than control. If the incubation studies were carried out for a longer period, say for one yr, the rate of C lost from the residues would be expected to approach the values in the control treatment.

These data show that under the same conditions (temperature, moisture, loading rate, size of the materials

Table 4-2. Carbon budget at 60 days of incubation and N concentration in the four residues and in soil.

Parameter	Control (No residue)	Residue Treatment @			
		Corn	Oat	Rye	Wheat
C:N ratio	11.6	38	77	75	80
(dag/kg) N	0.15	1.05	0.52	0.56	0.60
(dag/kg) C*	1.74	39.9	40.1	42.0	48.0
Total C (mg)	1740.00	99.75	100.25	105.00	120.00
Total initial C in the soil+ residue mixture (mg)	-	1839.75	1840.25	1845.00	1860.00
CO_2 -C evolved** (mg)	57.27	141.82	134.45	115.09	96.27
CO_2 -C evolved from residues (mg)	-	84.55	77.18	57.82	39.00
% CO_2 -C evolved from residues	-	84.8	77.0	55.1	32.5

@ The amount of residue added was 250 mg in 100g soil.

* Determined in the soil by Walkley and Black wet digestion, Allison (1965), and in the residues by the the method of Shaw (1959).

** Cumulative amount at 60 days incubation.

and soil type) the decomposition of corn residue was more rapid than oat, rye and wheat after 10 days of incubation. Residue decomposition was exponentially decreased with time as measured by the amount of CO_2 or CO_2-C evolved. The results also showed that the greater the C:N ratios the slower the decomposition rate (Table 4-2). These results are in agreement with the earlier results published by Gaur et al. (1971), Alexander (1977) and White (1984).

CO_2 Evolution of Soil-Residue Types and Rates

A similar technique was followed to evaluate the influence of residue rate on the rate of CO_2 evolution. Mean values of cumulative CO_2 at 60 days of incubation by different residue rates and types are presented in Figure 4-3. For each type of residue treatment the average amount of CO_2 evolved at different residue rates was different. These differences are shown by the LSD values at $P = 0.05$. The magnitude of the difference between the control (no residue) and residue rate 2.5 mt/ha was highest with corn residue and lowest in wheat residue.

Figure 4-3 shows that for all residue types, the trend of cumulative amount of CO_2 evolved at 60 days incubation as affected by residue rate was in the order of $7.5 > 5.0 > 2.5 > 0$ mt/ha. For each residue type, the percentage increase of cumulative CO_2 in every 2.5 mt/ha increment was

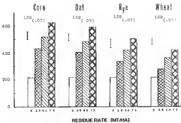


Figure 4 3. Effect of residue rate on the cumulative amount of CO_2 evolved at 60 days of incubation.

about the same (23%), except between control and 2.5 mt residue/ha. The percentage increase of CO_2 evolved between 0 and 2.5 mt/ha for corn, oat, rye and wheat residue treatment was about 38, 86, 55, and 29%, respectively.

A three dimensional relationship between the effect of residue rate and incubation time (days) on the cumulative amount of CO_2 evolved is shown in Figure 4-4. The cumulative CO_2 values were the average values of 4 residue types and 3 replicates. It was observed that at any residue rate, the cumulative CO_2 values were increased when the incubation time (days) was increased. The values were greater in the highest residue rate (7.5 mt/ha) than in the lowest residue rate (2.5 mt/ha).

Data obtained from this study are only within residue loading rates of 0-7.5 mt/ha. For rates higher than 7.5 mt/ha, the trend of CO_2 evolved cannot be predicted. In previous research, higher residue application rates decreased decomposition (Brown and Dickey, 1970; Broadbent and Bartholomew, 1949; Ruiz-Gimenez and Chase, 1984).

It is suggested that under the same environmental conditions the decomposition rates of corn, oat, rye and wheat residues within application rates of 0-7.5 mt/ha were increased (P = 0.05) when the residue rates were increased. Total cumulative CO_2 were highest for the 7.5 mt/ha of residue and lowest at 2.5 mt/ha of residue.

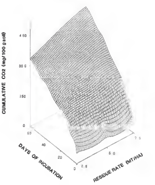


Figure 4-4. Three dimensional relationship between residue rate, days of incubation and cumulative amounts of CO_2 evolved during 60 days of incubation. The CO_2 values were the average of 3 replicates and 4 residue types.

CO_2 Evolution of Soil-Residue Types with N-Rates

To collaborate glasshouse studies involving N rates, the same N rates and source (NH_4NO_3) were used in the laboratory study. Effects of three N rates (0, 50, and 100 kg/ha) on the amount of cumulative CO_2 evolved in 60 days incubation are shown in Figure 4-5. In all residue treatments, increasing rates of N applied increased the amount of cumulative CO_2 evolved. However, in the control (no residue) treatment the effect was not significant. In the control treatment, most of the C in the soil was likely in the form of a ligno-protein complex which was not completely humified (Dr. T.L. Yuan, personal communication). Organic fractions in the soil were most resistant to decomposition while in the residue treated-soil some of the organic fractions were readily decomposed. Many researchers have reported that the addition of inorganic N did not influence the degradation of lignin in plant residues and soils (Alexander, 1977; Kononova, 1961, Lynch, 1979; Waksman and Gerretsen, 1931).

Figure 4-5 shows that the percentage increase in the amount of CO_2 evolved for every 50 kg N/ha for all residue types was about 12%. This implies that the decomposition of the residues was increased about the same percentage for every 50 kg N/ha added. It should be remembered that these results were only for the residue application rate 5.0 mt/ha

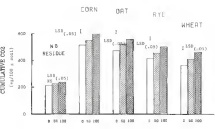


Figure 4-5. Effect of N rate on the cumulative amounts of CO_2 produced by five treatments. The loading rate of residues was 5.0 mt/ha.

Other rates of residue were not evaluated.

Results of this study show that the added inorganic N enhanced the decomposition of corn, oat, rye and wheat residues. Similar results were reported by Waksman and Gerretsen (1931) and Mass and Adamson (1972). Other reports showed that there was no effect of N on crop residue decomposition (Ruiz-Gimenez and Chase, 1984; Parr and Papendick, 1978; Smith and Douglas, 1971). Conflicting results may have been due to several factors such as temperature, moisture, soil type, source and rate of N, application rates, size and type of residue used, and methods of application to soils.

Conclusions

These three laboratory-incubation studies provide some quantitative information regarding the decomposition of residue in a sandy soil. Based on the quantities of CO_2 evolved, the decomposition of four residue types during 60 days of incubation were in the order of corn > oat > rye > wheat. But during the first 10 days incubation the rates of CO_2 evolve in descending order were oat > corn > rye > wheat. Decomposition of various residue types depends on the amount of available C in each residue types depends on the amount of available C in each residue. The higher the amount of available C, the greater the decomposition rate.

Residue rate also affected the amount of CO_2 evolved. Within the range of 2.5-7.5 mt residue/ha the amounts of CO_2 evolved were increased by the residue rate ($P = 0.05$). Decomposition of organic C in the soil alone was slower than the decomposition of soil plus residue mixtures. Residue decomposition rates based on CO_2 evolution per day were exponentially decreased with time.

Addition of inorganic N enhanced the residue decomposition at the residue rate 5.0 mt/ha. However, the decomposition of organic matter in the soil was not influenced by the addition of N. Soil organic matter contained C compounds which were resistant to decomposition.

CHAPTER 7
GENERAL SUMMARY AND CONCLUSIONS

Three glasshouse experiments were conducted to evaluate the effects of residue type and rates and N rates on soil fertility changes and corn growth. Crop residues used were corn, oat, rye and wheat. Residue rates applied were 0, 2.5, 5.0 and 7.5 mt/ha and N rates were 0, 50 and 100 kg/ha. The treatment combinations were arranged in a factorial experiment with a randomized complete block design and three replicates.

The first crop showed that dry matter production was reduced as compared to the second and third crop. Residue rate had no effect on plant dry weight in the first crop, but N rates increased plant dry matter weights. The corn residue treatment produced superior plant dry weight relative to the other three types of residues.

Plant P uptake in Crop 1 depended on all three factors (residue type, residue rates, and N rates). Corn tissue K uptake in Crop 1 was increased when residue rates were increased. For the residue rate treatment of 7.5 mt/ha, the K uptake was about 60% higher than in the control.

Soil pH in all three crops increased when the amount of residue applied increased. The highest pH was obtained from the residue rate of 7.5 mt/ha. The reduction of 1 M KCl exchangeable soil Al was related to the increase in pH by the addition of organic matter (plant residues). One [illegible] exchangeable Al was reduced when the amount of residue added increased.

In Crop 1, Mehlich I extractable Ca and Mg increased with increasing residue rates. Other nutrients (N, P, K, Fe, Cu, and Zn) were not affected by the residue rate. Soil Mg was highest in the wheat treatment and lowest in the rye treatment. Soil Cu was highest in the oat treatment and almost the same in corn, rye and wheat treatments.

In Crop 2, plant dry weight was increased by N rates. Increasing N rates from 0 to 100 kg/ha increased the plant dry weight about 50%. Mehlich I extractable soil K and Ca were dependent upon the residue rate and residue type.

In Crop 3, plant dry weight was dependent on residue type, residue rate, and N rate as indicated by a strong 3-way interaction in the ANOVA. Root dry weights were highest in the oat residue treatment and lowest in the wheat residue treatment. Shoot:root ratios were highest in the wheat residue treatment and lowest in the corn residue treatment. Treatment differences might be related to the nutrients released by crop residues in the soil. Mehlich I extractable P, Mg and Zn were found to be highest in corn, corn and wheat, and oat treatments, respectively. The amount of those extractable elements in soil was related to the original present in the residues.

Soil bulk density which was determined only at the end of Crop 3 decreased with increasing residue rates. This implies that increasing residue rates applied from 0 to 7.5 mt/ha improved soil structure and aeration and reduced compaction. The decrease in bulk density was from 1.29 Mg/m^3 to 1.21 Mg/m^3.

In laboratory incubation studies, during the first 32 days of incubation the amount of CO_2 released by different residues was in the descending order of oat > corn > rye > wheat > control (no residue). On the other hand, the trend was changed to corn > oat > rye > wheat > control when the incubation period was between 32-60 days. The shift of the trend by corn and oat residues was related to the amount of readily available C in the residues.

Generally, residue decomposition as measured by the amount of CO_2 or CO_2-C evolved was exponentially decreased with time. Decomposition of organic matter in the soil was only about 3.3%, while in corn, oat, rye and wheat treatments were 84.8, 77.0, 55.1 and 32.5%, respectively. This calculation was based on the amount of CO_2-C released from the original amount of C in the treatments and same residue rate applied (5.0 mt/ha).

For all types of residue, increasing rates of application increased the cumulative amounts of CO_2 during the 60 days of incubation. The percent increase of cumulative amount of CO_2 evolved between the control (no residue) and the residue rate of 2.5 mt/ha for corn, oat, rye and wheat were about 98, 86, 55 and 29%, respectively.

Addition of N enhanced the decomposition of corn, oat, rye and wheat residues. But, it did not influence the decomposition of organic matter in the soil with no residue added. Soil organic matter contained a high amount of resistant C. For every 50 kg N/ha added, the amount of CO_2-C evolved increased by about 12%.

From the results obtained in these studies, the following conclusions and recommendations can be drawn:

1. Corn residue generally contained higher nutrients than oat, rye and wheat. Therefore, among these residues corn is the best type to be used by farmers. Corn also decomposed faster than the other three residues.

2. Addition of crop residues to a sandy soil reduced the amount of 1 M KCl exchangeable soil Al and increased soil pH.

3. Plant corn about 2 months after residue incorporation. Planting earlier than this time caused a reduction in corn growth.

4. Addition of inorganic N enhanced the decomposition of these residues in the soil. A N rate of 50 kg/ha might be sufficient for corn residue but for oat, rye and wheat, N

rate of more than 100 kg/ha may be required to fulfil optimum corn growth.

APPENDIX

Table A-1. Analysis of variance of the treatment effects and their interactions on plant fresh and dry weights and selected plant nutrients concentration in Crop 1.

Source	df	Plant Fresh Weight	Plant Dry Weight	Tissue nutrients concentration N	P	K	Ca	Mg
		F values						
Residue Type (RT)	3	20.96**	2.60*	0.22	3.36*	0.10	1.27	1.88
Residue Rate (RR)	3	9.07**	1.99	0.56	5.05*	5.73**	0.87	1.15
RT X RR	9	4.35**	0.85	0.76	3.67*	0.41	1.33	1.21
N Rate (NR)	2	36.82**	4.04*	3.42*	9.36**	1.73	0.18	2.68
RT X NR	6	5.58**	0.76	0.57	0.48	0.60	1.42	1.88
RR X NR	6	15.65**	1.45	1.32	2.52*	1.20	2.01	2.02
RT X RR X NR	18	10.05**	0.67	0.45	2.36*	0.43	0.77	1.09
		C.V. (%)						
		5.69	19.4	10.3	24.2	16.5	22.9	28.5

** , * Significant at P = 0.01 and P = 0.05 , respectively.
df = degree of freedom.
C.V. = coefficient of variation.

Table A-2. Analysis of variance of the treatment effects and
interactions on selected corn plant nutrients uptake in Crop

Source	df	Tissue nutrients Uptake @				
		N	P	K	Ca	Mg
		F values				
Residue Type (RT)	3	0.55	4.78*	2.24	0.56	1.63
Residue Rate (RR)	3	0.73	5.77*	26.52**	0.44	1.24
RT X RR	9	1.30	2.59*	1.47	1.15	1.47
N Rate (NR)	2	3.63*	8.48**	1.78	0.29	2.65
RT X NR	6	0.43	0.28	0.62	0.99	1.11
RR X NR	6	0.64	2.21*	1.26	1.59	1.94
RT X RR X NR	18	0.35	2.78*	1.42	0.73	0.90
		C.V. (%)				
		11.32	18.82	12.06	25.53	19.05

**,* Significant at P = 0.01 and P = 0.05 , respectively.
df = degree of freedom.
C.V. = Coefficient of variations.
@ Nutrient uptake = Plant dry weight X tissue nutrient concentration.

Table A-3. Analysis of variance of the treatment effects and their interactions on soil pH, 1 M KCl exchangeable Al and Mehlich I extractable nutrients at the end of Crop 1.

		Soil pH (1:2)		1 M KCl	Mehlich I extractable						
Source	df	H_2O	1 M KCl	Exchg. Al	P	K	Ca	Mg	Fe	Cu	Zn
		F values									
Residue Type (RT)	3	6.12**	10.65**	5.60**	1.42	0.48	0.66	2.60*	1.22	3.08*	0.75
Residue Rate (RR)	3	111.27**	90.74**	2.62	0.39	1.76	6.67**	6.23**	0.51	1.25	1.22
RT X RR	9	0.65	1.75	1.89	0.94	0.65	0.49	1.40	1.17	1.15	0.42
N Rate (NR)	2	0.24	2.51	4.74**	0.24	1.26	2.10	3.23*	2.10	1.02	0.71
RT X NR	6	0.30	0.77	1.19	0.42	0.79	1.13	1.19	0.34	0.99	0.15
RR X NR	6	0.29	4.21	1.46	2.09	0.30	0.81	1.35	1.05	1.15	0.99
RT X RR X NR	18	0.49	1.22	10.29**	0.71	0.79	0.84	0.86	0.65	0.76	0.59
		C.V.(%)									
		1.26	0.63	10.87	22.1	9.05	14.5	18.2	16.4	12.9	15.5

**,* Significant at P =0.01 and P = 0.05, respectively.
C.V. = Coefficient of variation.
df = Degree of freedom.

Table A-4. Analysis of variance of the treatment effects and their interactions on plant dry weight, soil pH and Mehlich I extractable nutrients at the end of Crop 2.

Source	df	Plant dry weight	Soil pH (1 2)		Mehlich I extractable						
			H_2O	1M KCl	P	K	Ca	Mg	Fe	Cu	Zn
		F values									
Residue Type (RT)	3	0.36	0.50	1.43	2.02	2.05	1.63	1.64	4.15**	0.59	0.52
Residue Rate (RR)	3	1.14	8.26**	4.46**	0.83	1.62	3.50*	3.48*	1.19	1.14	1.56
RT X RR	9	1.39	0.90	0.60	1.21	2.14*	2.14*	1.10	0.64	0.67	0.44
N Rate (NR)	2	12.11**	1.19	1.64	2.59	0.55	0.59	2.63	2.39	0.20	1.13
RT X NR	6	0.62	0.83	0.31	1.70	0.92	1.03	0.54	0.55	0.39	0.24
RR X NR	6	1.14	1.35	0.83	1.08	0.34	1.86	0.56	1.32	1.75	0.74
RT X RR X NR	18	1.27	0.71	0.56	0.61	1.01	0.68	0.50	0.77	1.33	0.95
		C.V. (%)									
		13.97	2.98	1.70	22.08	6.56	16.99	24.89	15.47	6.23	6.80

**,* Significant at P = 0.01 and P = 0.05, respectively.
df = degree of freedom.
C.V. = Coefficient of variation.

Table A-5. Analysis of variance of the treatment effects and their interactions on plant fresh and dry weights, root dry weight, shoot:root ratio and soil bulk density at the end of Crop 3.

Source	df	Plant		Root dry wt.	Shoot:Root ratio	Bulk density
		Fresh Wt.	Dry Wt.			
		F values				
Residue Type (RT)	3	3.45*	2.15*	3.41*	3.32*	2.06
Residue Rate (RR)	3	0.31	0.30	0.08	0.18	9.91**
RT X RR	9	2.07*	2.24*	0.48	0.96	0.87
N Rate (NR)	2	0.88	1.52	2.15	1.09	0.14
RT X NR	6	1.60	1.08	0.61	0.92	0.49
RR X NR	6	1.21	3.05**	0.53	1.44	1.89
RT X RR X NR	18	1.40	2.68**	0.51	0.64	1.07
		C.V. (%)				
		10.42	8.99	13.98	16.77	5.46

**,* Significant at P = 0.01 and P = 0.05, respectively.
df = degree of freedom.
C.V. = Coefficient of variations.

Table A-6. Analysis of variance of the treatment effects and their interactions on soil pH and Mehlich I extractable nutrients at the end of Crop 3.

Source	df	Soil pH (1:1)		1 M KCl exch. Al	Mehlich 1 extractable						
		H_2O	1 M KCl		P	K	Ca	Mg	Fe	Cu	Zn
					F values						
Residues Type (RT)	3	0.67	0.79	5.34*	4.82**	0.48	1.53	3.51*	1.15	0.57	8.11**
Residues Rate (RR)	3	22.35**	14.13**	5.21*	0.48	2.05*	1.17	1.92	0.39	0.66	2.12*
RT X RR	9	1.39	2.24	1.41	0.77	1.74	0.52	1.40	0.26	1.46	0.53
N Rate (NR)	2	2.18	3.39	3.21	0.49	3.28*	2.49	1.63	1.61	0.80	0.86
RT X NR	6	0.45	1.18	1.50	0.89	1.23	0.91	1.29	0.84	0.33	0.57
RR X NR	6	5.45*	4.50*	11.21*	0.21	1.29	1.95	2.15	1.22	0.63	1.7[illegible]
RT X RR X NR	18	0.54	0.64	2.11	0.51	1.31	0.60	1.01	0.90	0.85	1.11
					C.V. (%)						
		1.63	0.84	11.20	10.00	20.73	15.42	15.07	8.53	16.45	24.12

**, * Significant at P = 0.01 and P = 0.05, respectively.
df = degree of freedom.
C.V. = coefficient of variations.

LITERATURE CITED

Acharya, C. N. 1935. Studies on the anaerobic decomposition of plant materials III. Comparison of the course of decomposition under anaerobic, aerobic and partially aerobic conditions. Biochem. J. 29.1116-1120.

Adams, J. E 1965. Effects of mulches on soil temperature and grain sorghum development. Agron. J. 57:471-474.

Ahmad, F., and K. H. Tan. 1986. Effect of organic matter on soybean seedlings grown in aluminium-toxic soil. Soil Sci. Soc. Amer. J. 50:656-661.

Alexander, M. 1977. Introduction to Soil Microbiology. 2nd edition. John Wiley and Sons, New York, N Y.

Allison, F. E. 1965. Organic carbon. p. 1367-1378. In C. A. Black (ed.). Methods of Soil Analysis -- Part 2. Agronomy No. 9 Amer. Soc. Agron., Madison, WI.

Allison, F. E., and R. G. Cover. 1960. Rates of decomposition of short leaf pine sawdust in soil at various levels of nitrogen and lime. Soil Sci. 89: 194-201.

Allmaras, R. R., A. L. Black and R. W. Rickman. 1973. Tillage, soil environment, and root growth. p. 62-86. Soil Conserv. Soc. Amer. (ed.). In Conservation Tillage Proc. Natl. Conf. Des Moines, IA. 28-30 March 1973. Soil Conserv. Soc. Amer., Ankeny, IA.

Amato, M., R. B. Jackson, J. B. A. Butler and J. N. Ladd. 1984. Decomposition of plant material in Australian soils II. Residual organic C and N from legume plant parts decomposing under field and laboratory conditions. Aust. J. Soil Res. 22:331-341.

Aulakh, M. S., D. A. Rennie, and E. A. Paul. 1984. The influence of plant residues on denitrification rates in conventional and zero tilled soils. Soil Sci. Soc. Amer. J. 48:790-794.

Balasubramanian, V., and L. A. Nnadi. 1980. Crop residue management and soil productivity in savanna area of Nigeria. p. 106-120. In FAO (ed.). Organic Recycling in Africa. FAO Soils Bulletin No. 43. FAO, Rome, Italy.

Barber, S. A. 1979. Corn residue management and soil organi matter. Agron. J. 71.825-827.

Barber, S. A. 1984. Soil Nutrient Bioavailability. A Mechanistic Approach. John Wiley and Sons, New York, NY.

Barr, A. J., J. B. Goodnight, J. P. Sall, W. H. Blair and D. M. Chilko. 1979. SAS User's Guide. 1979 edition. SAS Institute Inc., Cary, NC.

Bartholomew, W. V. 1965. Mineralization and immobilization of nitrogen in the decomposition of plant and animal residues. p. 287-308. In W. V. Bartholomew and F. C. Clark (eds.). Soil Nitrogen. Agronomy 10. Amer. Soc. of Agron. Madison, WI.

Bhatnagar, V. K., T. N. Chaudhry, and B. R. Sharma. 1983. Effect of tillage and residue management on properties of two coarse-textured soils and on yield of irrigated wheat and groundnut. Soil and Tillage Res. 3:27-37.

Birch, H. F. 1958. The effect of soil drying on humus decomposition and nitrogen availability. Plant and Soil 10(1):9-31.

Black, A. L. 1970. Soil water and soil temperature influences on dryland winter wheat. Agron. J. 82:797-801.

Black, A. L. 1973 a. Crop residue, soil water, and soil fertility related to spring wheat production and quality after fallow. Soil Sci. Soc. Amer. Proc. 37:754-758.

Black, A. L. 1973 b. Soil property changes associated with crop residue management in a wheat-fallow rotation. Soil Sci. Soc. Amer. Proc. 37:943-946.

Black, A. L. and F. H. Siddoway. 1979. Influence of tillage and wheat straw residue management on soil properties in the Great Plains. J. Soil and Water Conserv. 34(5):220-223.

Blair, G. J., and O. W. Boland. 1978. The release of phosphorus from plant material added to soil. Aust. J. Soil Res. 16:101-111.

Blake, G. R. 1965. Bulk density. p. 374-390, In C. A. Black (ed.). Methods of Soil Analysis --Part i. Agron. series No. 9., Amer. Soc. Agron., Madison, WI

Blevins, R. L., M. S. Smith, G. W. Thomas, and W. W. Fry. 1983. Influence of conservation, tillage on soil properties. J. Soil and Water Conserv. 38(3):301-305.

Bloom, P. R. 1981. Metal-organic matter interactions in soil. p. 129-150, In M. Stelly (ed.). Chemistry in the Soil Environment. Amer. Soc. Agron. Special Pub. No. 40. Amer. Soc. Agron. and Soil Sci. Amer., Madison, WI.

Bond, J. J., and W. O. Willis. 1969. Soil water evaporation: Surface residue rate and placement effects. Soil Sci. Soc. Amer. Proc. 33:445-448.

Bond, J. J., and W. O. Willis. 1971. Soil water evaporation: Long term drying as influenced by surface residue and evaporation potential. Soil Sci. Soc. Amer. Proc. 35:984-987.

Boote, K. J. 1977. Root:shoot relationships. Soil Crop Sci. Soc. Fla. Proc. 36:15-23.

Borst, H. L., and H. J. Mederski. 1957. Surface mulches and mulch tillage for corn production. Ohio Agric. Exp. St. Res. Bull. 796:1-19.

Brady, N. C. 1984. The Nature and Properties of Soils. 9th edition. Macmillan Pub. Co., New York, NY.

Bremner, J. M. 1965. Total nitrogen. p. 1149-1179. In C. A. Black (ed.). Methods of Soil Analysis --Part 2. Amer. Soc. Agron., Madison, WI.

Broadbent, F. E. 1957. Organic matter in soil. USDA Yearbook, Washington, DC.

Broadbent, F. E., and W. V. Bartholomew. 1949. The effect of quantity of plant material added on the rate of decomposition. Soil Sci. Soc. Amer. Proc. 13:271-274.

Brown, M. J. 1985. Effect of grain straw and furrow irrigation stream size on soil erosion and infiltration. J. Soil and Water Conserv. 40(4):389-391.

Brown, P. L., and D. T. Dickey. 1970. Losses of wheat straw residue under simulated conditions. Soil Sci. Soc. Amer. Proc. 34:118-121.

Burrows, W. C., and W. E. Larson. 1962. Effect of amount of mulch on soil temperature and early growth of corn. Agron. J. 54:19-23.

Carlson, C. A. 1985. Wildlife and agriculture Can they coexist? J. Soil and Water Conserv. 40(3):283-266.

Chew, V. 1976. Comparing treatment means: A compendium. Hort. Sci. 11:348-357.

Christensen, B. T. 1985. Decomposability of barley straw: Effect of cold-water extraction on dry weight and nutrient content. Soil Biol. Biochem. 17:93-97.

Cochran, V. L., L. F. Elliot, and R. I. Papendick. 1980. Carbon and nitrogen movement from surface-applied wheat (*Triticum aestivum*) straw. Soil Sci. Soc. Amer. J. 44:978-982.

Coleman, N. T., and G. W. Thomas. 1967. The basic chemistry of soil acidity. p. 1-41. *In* R. W. Pearson and F. Adams (eds.). Soil Acidity and *Liming*. Agronomy No. 9. Amer. Soc. Agron., Madison, WI.

Coleman, N. T., S. B. Weed, and R. J. Mc Craken. 1959. Cation exchange capacity and exchangeable cations in Piedmont soils of North Carolina. Soil Sci. Soc. Amer. Proc. 23:146-149.

Cook, R. J., M. G. Boosalis, and B. Doupnik. 178. Influence of crop residues on plant diseases. p. 147-164. *In* W. R. Oschwald (ed.). Crop Residue Management *Systems*. ASA special Pub. No. 31, Amer. Soc. Agron., Madison, WI.

Council, K. A., and J. T. Helwig. 1981. SAS/Graph User's Guide. SAS Institute, Inc., Cary, NC.

Cruse, R. M. 1985. Watch soil temperatures. Managing crop residues brings several benefits. Crop and Soils 38(3):17-18.

Doran, J. W. 1980. Microbial changes associated with residue management with reduced tillage. Soil Sci. Soc. Amer. J. 44:518-524.

Doran, J. W., W. W. Wilhelm, and J. F. Power. 1984. Crop residue removal and soil productivity with no-till corn, sorghum and soybean. Soil Sci. Soc. Amer. J. 48:640-645.

Douglas, Jr. C. L., R. R. Allmaras, P. E. Rasmussen, R. E. Ramig, and M. C. Roager, Jr. 1980. Wheat straw composition and placement effects on decomposition in dryland agriculture of the Pacific Northwest. Soil Sci. Soc. Amer. J. 44:833-837.

Duley, F. L. 1960. Yields in different cropping systems and fertilizer tests under stubble mulching and plowing in eastern Nebraska. Nebraska Agric. Exp. Stn. Res. Bull. 190:1-53.

Duley, F. L., and J. C. Russel. 1948. Stubble mulch farming. USDA Farmer's Bull. 1997:3-32.

Elliott, L. F., and J. W. Blaylock. 1975. Effects of wheat straw and alfalfa amendments on solubilization of manganese and iron in soil. Soil Sci. 120:205-211.

Elliott, L. F., T. M. Mc Calla, and A. Waiss, Jr. 1978. Phytotoxicity associated with residue management. p. 131-146. In W. R. Oschwald (ed.). Crop Residue Management Systems. Amer. Soc. Agron. Special Pub. No. 31. Amer. Soc. Agron., Madison, WI.

El-Swaify, S. A., and A. H. Sayegh. 1975. Charge characteristics of an oxisol and Inceptisol in Hawaii. Soil Sci. 120:49-56.

Fairbourn, M. L., and H. R. Gardner. 1972. Vertical mulch effects on soil water storage. Soil Sci. Soc. Amer. Proc. 36:823-827.

Fenster, C. R., R. B. Follett, and E. J. Williamson. 1978. Best use of crop residues. Crop and Soils 30(9):10-13.

Ferguson, W. S. 1967. Effect of repeated applications of straw on grain yields and on some soil properties. Can. J. Soil Sci. 47:117-121.

Gallaher, R. N. 1980. Value of residues, mulches of sods in cropping system. IFAS Publication MMT-5, University of Florida, Gainesville, FL.

Gaur, A. C, K. V. Sadasivam, O. P. Vimal, and R. S. Mathur. 1971. A study on the decomposition of organic matter in an alluvial soil: CO evolution, microbiological and chemical transformations. Plant and Soil 34:17-28.

Greb, B. E. Smika, and A. L. Black. 1967 Effect of straw mulch rates on soil water storage during summer fallow in the Great Plains. Soil Sci. Amer. Proc. 31:556-559.

Greb, B. W., D. E. Smika, and A. L. Black. 1970. Water conservation with stubble mulch fallow. J. Soil and Water Conserv. 25:58-62.

Greenland, D. J. 1975. Bringing the green revolution to the shifting cultivator. Science 190.841-844.

Guenzi, W. D., and T. M. McCalla. 1962. Inhibitors of germination and seedling development by crop residues. Soil Sci. Soc. Amer. Proc. 26:456-458.

Gupta, S. C., J. K. Radke, and W. E. Larson. 1981. Predicting temperatures of bare and residue covered soils with and without a corn crop. Soil Sci. Soc. Amer. J. 45:405-412.

Hairston, J. E., J. O. Sanford, and J. C. Hayes. 1984. Effect of wheat straw management and supplemental nitrogen on growth and yield of double crop soybeans. MAFES Res. Report Vol. 9 No. 11. Mississippi State University, MS.

Hallam, M. J., and W. V. Bartholomew. 1953. Influence of rate of plant residue addition in accelerating the decomposition of soil organic matter. Soil Sci. Soc. Amer. Proc. 17:365-368.

Halstead, R. L., and F. J. Sowden. 1968. Effect of Long-term additions of organic matter on crop yields and soil properties. Can. J. Soil Sci. 48:341-348.

Hargrove, W. L., and G. W. Thomas. 1981. Effect of organic matter on exchangeable Al and plant growth in acid soils. p. 151-166. In M. Stelly (ed.). Chemistry in the Soil Environment. Amer. Soc. Agron. Special Pub. No. 40. Amer. Soc. Agron. and Soil Sci. Soc. Amer., Madison, WI.

Harmsen, G. W., and D. A. Van Schreven. 1955. Mineralization of organic nitrogen in soil. p. 299-398. In A. G. Norman (ed.). Advances in Agronomy, Vol. 7. Academic Press. Inc. Pub., New York, NY.

Harper, S. H. T., and J. M. Lynch. 1982. The role of water soluble components in phytotoxicity from decomposing straw. Plant and Soil 65:11-17.

Hausenbuiller, R. L. 1978. Soil Science, Principles and Practices, 2nd edition. Wm. C. Brown Co. Pub., Dubuque, IA, pp. 49-72.

Hegde, B. R., G. V. Havangi, N. Munikrishna Reddy, N. Venugopal, A. P. Vishwanath, and T. Satyanarayana. 1982. Studies on the incorporation of maize residue on soil properties and yield of maize under rainfed conditions. Ind. J. Agron. 27(3):254-258.

Hendrickson, O. Q. 1985. Variation in the C:N ratio of substrate mineralized during forest humus decomposition. Soil Biol. Biochem. 17:435-440.

Herman, W. A., W. B. McGill, and J. F. Dormaar. 1977. Effects of initial chemical composition on decomposition of roots of three grass species. Can. J. Soil Sci. 57:205-215.

Hooker, M. L., G. M. Herron, and P. Penas. 1982. Effects of residue burning, removal, and incorporation on irrigated cereal crop yields and soil chemical properties. Soil Sci. Soc. Amer. J. 46:122-126.

Hovermale, C. H. 1983. The effect of cover crop, tillage method, and residue management on soybean yield in south Mississippi. MAFES Research Report Vol. 8 No. 13. Mississippi State University, MS.

Izza, C. and R. Indiati. 1982. Effect of farm organic residues added to the soil on phosphorus sorption. Annali dell's Instituto Sperimentale per la Nutrizione delle Piante 11(6):21 pp.

Iverson, K. C. 1973. Fungal flora and rate of decomposition of leaf litter at low temperatures. Can. J. Soil Sci. 53:79-84.

Jackson, M. G. 1977. The alkali treatment of straws - A review. Animal Feed Sci. Technol. 2:105-130.

Jackson, M. L. 1965. Clay transformation in soil genesis during quarternary. Soil Sci. 99:15-22.

Jawson, M. D., and L. F. Elliott. 1986. Carbon and nitrogen transformations during wheat straw and root decomposition. Soil Biol Biochem. 18:15-22.

Jenkinson, D. S. 1977a. Studies on the decomposition of plant material in soil IV. The effect of rate of addition. J. of Soil Sci. 28:417-423.

Jenkinson, D. S. 1977 b. Studies on the decomposition of plant material in soil V. The effects of plant cover and soil type on the loss of carbon from labelled ryegrass decomposing under field conditions. J. of Soil Sci. 28:424-434.

Jenkinson, D. S. 1981. The fate of plant and animal residues in soil. p. 505-561. In D. J. Greenland and M. B. B. Hayes (eds.). The Chemistry of Soil Processes. John Wiley and Sons, New York, NY.

Johnson, W. C. 1950. Stubble mulch farming on wheatlands of the Southern High Plains. Circ. 860. USDA. Washington, DC.

Jones, J. B. Jr. 1967. Interpretation of plant analysis for several agronomic crops. p. 49-58. In M. Stelly (ed.). Soil Testing and Plant Analysis --Part II. Plant analysis. Special Pub. No. 2. Soil Sci. Soc. Amer., Madison, WI.

Kamprath, E. J. 1970. Exchangeable aluminium as a criterion for liming leached mineral soil. Soil Sci. Soc. Amer. Proc. 34:252-254.

Karlen, D. L., P. G. Hunt, and R. B. Campbell. 1984. Crop residue removal effects on corn yield and fertility of a Norfolk sandy loam. Soil Sci. Soc. Amer. J. 48:868-872.

Ketcheson, J. W., and E. G. Beauchamp. 1978. Effects of corn stover manure, and nitrogen on soil properties and crop yield. Agron. J. 70:792-797.

Kidder, G. and R. D. Rhue. 1983. Interpretation of micronutrient soil tests. Notes in soil science No. 9. IFAS Pub., University of Fla., Gainesville, FL.

Knapp, E. B., L. F. Elliott and G. S. Campbell 1983 a. Microbial respiration and growth during the decomposition of wheat straw. Soil Biol. Biochem. 15:319-323.

Knapp, E. B., L. F. Elliott and G. S. Campbell 1983 o Carbon, nitrogen and microbial biomass straw: A mechanistic simulation model. Soil Biol. Biochem. 15:455-461.

Kononova, M. S. 1961. Soil Organic Matter. Its nature, Its Role in Soil Formation and in Soil Fertility. Pergamon Press Ltd., London, UK.

Koshi, P. T., and D. W. Fryrear. 1973. Effect of tractor traffic, surface mulch, and seedbed configuration on soil properties. Soil Sci. Soc. Amer. Proc. 37:758-762.

Ladd, J. N. 1981. The use of N in following organic matter turnover, with specific reference to rotation systems. Plant and Soil 48:401-411.

Larson, W. E., C. E. Clapp, W. B. Pierre and Y. B. Morachan. 1972. Effects of increasing amounts of organic residues on continuous corn II: Organic carbon, nitrogen, phosphorus and sulfur. Agron. J. 64:204-208.

Larson, W. E., R. F. Holt and C. W. Carlson. 1978. Residues for soil conservation. p. 1-17. *In* W. R. Oschwald (ed.). Crop Residue Management Systems. ASA Spec. Pub. No. 31. Amer. Soc. Agron., Madison, WI.

Lal, R. 1974. Soil temperature, soil moisture, and maize yield from mulched and unmulched tropical soils. Plant and Soil 40:129-143.

Lessiter, F. 1985. Look for a big no-tillage increase for 1985. No-till Farmer Magazine. Vol. 14 No. 6, p. 8-9.

Levashkevich, G. A. 1966. The interaction of humic acids with hydroxides of iron and aluminium. Pochvovedenie 4:58-65.

Lindsay, W. L. 1979. Chemical Equilibria in Soils. John Wiley and Sons, New York, NY.

Little, T. M., and F. J. Hills. 1978. Agricultural experimentation. Design and analysis. John Wiley and Sons, New York, NY.

Lynch, J. M. 1979. Straw residues as substrates for growth product formation by soil microorganisms. p. 47-56. *In* E. Grossbard (ed.): Straw Decay and Its Effect on Disposal and Utilization. Proceedings of a symposium on straw decay and workshop and assessment technique. John Wiley and Sons, New York, NY.

Maas, E. F., and R. M. Adamson. 1972. Resistance of sawdust, peats and bark to decomposition in the presence of soil and nutrient solution. Soil Sci. Soc. Amer. Proc. 36:769-772.

Mackay, A. D., and E. J. Kladivko. 1985. Earthworms and rate of breakdown of soybean and maize residues in soil. Soil Biol. Biochem. 17(6):851-857.

Mackenzie, R.C. 1975. The classification of soil silicates and oxides. p. 1-25. *In* G. E. Giesenking (ed.). Soil Components, Vol. 2. Springer-Verlag, New York, NY.

Mannering, J. V., and L. D. Meyer. 1963. The effects of various rates of surface mulch on infiltration and erosion. Soil Sci. Soc. Amer. Proc. 27:84-86.

Mathews, O. R. 1945. Crop residue management in dryland crop production. J. Amer. Soc. Agron. 37:297-306.

McBride, M. B. 1978. Transition metal bonding in humic acid: An ESR study. Soil Sci. 126:200-209.

McCalla, T. M., and F. A. Haskins. 1964. Phytotoxicity substances from soil microorganisms and crop residues. Bacteriological Reviews 28:181-207.

Mehlich, A. 1953. Determination of P, Ca, Mg, K, Na and NH_4 by North Carolina Soil Testing Laboratories. Univ. of N. Carolina, Raleigh, NC.

Moody, J. E., J. N. Jones, Jr., and J. H. Lillard. 1963. Influence of straw mulch on soil moisture, soil temperature and the growth of corn. Soil Sci. Soc. Am. Proc. 27:700-703.

Sorachan, Y. B., W. C. Moldenhauer, and W. E. Larson. 1972. Effects of increasing amounts of organic residues on continuous corn, I. Yield and soil physical properties. Agron. J. 64:199-203.

Morrison, R. T., and R. N. Boyd. 1974. Organic Chemistry. 3rd edition, Allyn and Bacon Inc., Boston, MA.

Musick, G. J., and L. E. Beasley. 1978. Effect of crop residue system on pest problems in field corn (Zea mays L.) production. P. 173-186 In W. R. Oschwald (ed.). Crop Residue Management Systems. ASA Special Pub. No. 31. Amer. Soc. Agron., Madison, WI.

Nelson, D. W., and L. E. Sommers. 1973. Determination of total nitrogen in plant material. Agron. J. 65:109-112.

Obreza, T. A., F. M. Rhoads, and R. L. Stanley, Jr. 1982. Effect of phosphorus levels on phosphorus deficiency symptoms and growth of three corn hybrids. Soil Crop Sci. Soc. Fla. Proc. 41:185-188.

Onderdonk, J. J., and J. W. Ketcheson. 1973. Effect of stover mulch on soil temperature, corn root weight, and phosphorus fertilizer uptake. Soil Sci. Soc. Amer. Proc. 37:904-906.

Oveson, M. M. 1966. Conservation of soil nitrogen in a wheat-summer fallow farming practice. Agron. J. 58:444-447.

Parker, D. T. 1962. Decomposition in the field of buried and surface applied corn stalk residues. Soil Sci. Soc. Amer. Proc. 26:559-562.

Parker, D. T., and W. E. Larson. 1962. Crop residue placement in soil and its effect upon growth of corn. Agron. J. 54:263-267.

Parr, J. F., and R. I. Papendick. 1978. Factors affecting the decomposition of crop residues by microorganisms. p. 101-129. In W. R. Oschwald (ed.). Crop Residue Management Systems. ASA Special Pub. No. 31, Amer.Soc. Agron., Madison, WI.

Pathak, B. S., A. K. Jain, and A. Singh. 1986. Characteristics of crop residues. Agricultural Wastes 16:27-35.

Patrick, Z. A. 1971. Phytotoxic substances associated with the decomposition in soil of plant residues. Soil Sci. 111:13-18.

Pikul, J. L., Jr., and R. R. Allmaras. 1986. Physical and chemical properties of a Haploxeroll after fifty years of residue management. Soil Sci. Soc. Amer. J. 50:214-219.

Pinck, L. A., F. E. Allison, and M. W. Sherman. 1950. Maintenance of soil organic matter. II. Losses of carbon and nitrogen from young and mature plant materials during decomposition in soil. Soil Sci. 69:391-401.

Pionke, H. B., and R. B. Corey. 1967. Relations between acidic aluminium and soil pH, clay and organic matter. Soil Sci. Soc. Amer. Proc. 31:749-752.

Ruiz-Gimenez, M. H., and F. E. Chase. 1984. Laboratory studies of factors affecting microbial degradation of wheat straw residues in soil. Can. J. Soil Sci. 64:9-19.

Rasmussen, P. E., R. R. Allmaras, C. R. Rohde, and N. C. Roager, Jr. 1980. Crop residue influences on soil carbon and nitrogen in a wheat-fallow system. Soil Sci. Soc. Amer. J. 44:596-600.

Reddy, K. R., and W. H. Patrick, Jr. 1975. Effect of alternate aerobic and anaerobic conditions in redox potential, organic matter decomposition and nitrogen loss in a flooded soil. Soil Biol. Biochem. 7:87-94.

Reddy, K. R., R. Khaleel, and M. R. Overcash. 1980. Carbon transformation in the land areas receiving organic wastes in relation to nonpoint source pollution. A conceptual model. J. Environ. Qual. 9:434-442.

Reinertsen, S. A., L. F. Elliott, V. L. Cochran, and G. S. Campbell. 1984. Role of available carbon and nitrogen in determining the rate of wheat straw decomposition. Soil Biol. Biochem. 16:459-4 Reviews 28:181-207.

Rhue, R. D., and G. Kidder. 1983. Procedures used by the IFAS Extension Soil Testing Laboratory and Interpretation of results. Circular 596, IFAS Pub., University of Florida, Gainesville, FL.

Rhue, R. D., and J. B. Sartain. 1979. A survey of the fertility status of Florida soils as indicated by selected soil test and results. Soil and Crop Sci. Soc. Fla. 38:112-116.

Richards, L. A. 1965. Physical condition of water in soil. p. 128-152. In C. A. Black (ed.). Methods of Soil Analysis --Part 1. Amer. Soc. Agron., Madison, WI.

Robertson, W. K. 1977. Crop residues. Soil Science Fact Sheet SL-13. IFAS Pub., University of Florida, Gainesville, FL.

Roper, M. M. 1985. Straw decomposition and nitrogenase activity (C_2H_2 reduction). Effects of soil moisture and temperature. Soil Biol. Biochem. 17:65-71.

Sanford, J. O., and J. E. Hairston. 1984. Double cropping: Nitrogen rates and timing for wheat following soybeans and grain sorghum. MAFES Research Report. Vol. 9 No. 13. Mississippi State University, MS.

Sanford, J. O., and L. L. Reinschmiedt. 1982. Soybean-Wheat double cropping. Tillage and straw management. MAFES Research Report Vol. 7 No. 14. Mississippi State University, MS.

SAS Institute Inc. 1982. SAS User's Guide: Statistics. SAS Institute Inc., Cary, NC.

SAS Institute Inc. 1985. SAS User's Guide. Statistics, Version 5 edition. SAS Institute Inc., Cary, NC.

Schnitzer, M., and E. H. Hanson. 1970. Organic-metallic interactions in soils:8. An evaluation on methods for the determination of stability constants of metal fulvic acid complex. Soil Sci. 109:333-340.

Schnitzer, M., and H. Kodama. 1977. Reactions of minerals with soil humic substances. Chapter 21, p. 741-770. In J. B. Dixon and S. B. Weed (eds.). Minerals in Soil Environments. Soil Sci. Amer., Madison, WI.

Schnitzer, M., and S. I. M. Skinner. 1965. Organo-metallic interaction in soils:4. Carboxyl and hydroxyl groups in organic matter and metal retention. Soil Sci. 99:278-284.

Shaw, K. 1959. Determination of organic carbon in soil and plant material. J. Soil Sci. 10:316-326.

Shields, J. A., and E. A. Paul. 1973. Decomposition of C-labelled plant material under field conditions. Can. J. Soil Sci. Soc. Amer. Proc. 53:297-306.

Siddoway, F. H. 1963. Effects of cropping and tillage methods on dry aggregate soil structure. Soil Sci. Amer. Proc. 27:452-454.

Singh, B. B., and J. P. Jones, 1976. Phosphorus sorption and desorption characteristics of soil as affected by organic residues. Soil Sci. Soc. Amer. J. 40:389-394.

Singh, C., N. T. Singh and M. R. Chaudhary. 1976. Effect of mulch-induced hydrothermal regimes on root growth in the case of maize. Indian J. Ecol. 3:141-148.

Skidmore, E. L., and F. H. Siddoway. 1978. Crop residue requirements to control wind erosion. p. 17-34/ In W. R. Oschwald (ed.). Crop Residue Management Systems. ASA Special Pub. No. 31. Amer. Soc. Agron., Madison, WI.

Smika, D. E., A. L. Black, and B. W. Greb. 1969. Soil nitrate, soil water, and grain yields in a wheat-fallow rotation in the Great Plains as influenced by straw mulch. Agron. J. 61:785-787.

Smith, J. B. 1966. Some interrelationships between decomposition of various plant residues and loss of soil organic matter as measured by Carbon-14 labeling. p. 223-233. In FAO/IAEA (eds.). The Use of Isotopes in Soil Organic Matter Studies. Pergamon Press, Oxford, England.

Smith, J. H., and C. L. Douglas. 1971. Wheat straw decomposition in the field. Soil Sci. Soc. Amer. Proc. 35:269-272.

Smith, J. H., and R. E. Peckenpaugh. 1986. Straw decomposition in irrigated soil: Comparison of twenty-three cereal straws. Soil Sci. Soc. Amer. J. 50:928-932.

Soil Survey Staff. 1975. Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys. USDA Agric. Handbook No. 436. US Govt. Printing Office, Washington, DC.

Stacey, M. 1976. Straw as a potential raw material for chemicals. Agric. Prog. 51:69-75.

Staniforth, A. R. 1979. Cereal straw. Clarendon Press, Oxford, England.

Stevenson, F. J. 1982. Humus chemistry. Genesis, composition, reaction. John Wiley and Sons, New York, NY.

Stotzky, G. 1965. Microbial respiration. p. 1550-1572. In C. A. Black (ed.). Methods of Soil Analysis --Part 2. Agronomy series No. 9. Amer. Soc. Agron, Madison, WI.

Tan, K. H. 1986. Degradation of soil minerals by organic acids. p. 1-27, In P. M. Huang and M. Schnitzer (eds.). Interactions of Soil Minerals With Natural Organics and Microbes. Special Pub. No. 17. Soil Sci. Soc. Amer., Madison, WI.

Tanaka, A. 1973. Methods of handling rice straw in various countries. International Rice Commission Newsletter. FAO, Bangkok, Thailand.

Tenny, F. G., and S. A. Waksman. 1930. Composition of material organic materials and decomposition in the soil V. Decomposition of various chemical constituents in plant materials under anaerobic conditions. Soil Sci. 30:143-160.

Tisdale, S. L., W. L. Nelson, and J. D. Beaton. 1985. Soil Fertility and Fertilizers, 4th edition. Macmillan Pub. Co., New York, NY.

Uehara, G. and G. Gillman. 1981. The Mineralogy, Chemistry and Physics of Tropical Soils with Variable Charge Clays. Westview Press, Boulder, CO.

Undersander, D. J., and Reiger. 1985. Effect of wheat residue management on continuous production of irrigated winter wheat. Agron. J. 77:508-511.

Unger, P. W. 1968. Soil organic matter and nitrogen changes during 24 years of dryland wheat tillage and cropping practices. Soil Sci. Soc. Amer. Proc. 32:427-429.

Unger, P. W. 1978. Straw mulch rate effect on soil water storage during fallow and grain sorghum growth and yield. Soil Sci. Soc. Amer. J. 42:486-491

Unger, P. W., and A. F. Wiese. 1979. Managing irrigated winter wheat residues for water storage and subsequent dryland grain sorghum production. Soil Sci. Soc. Amer. J. 43:582-588.

USDA, Office of Planning and Evaluation. 1975. Minimum tillage. A preliminary technology assessment. Part II of a report for the committee on Agriculture and Forestry, United States Senate, Pub. No. 57-398, Govt. Printing Office, Washington, DC.

Van Wijk, W. R., W. E. Larson, and W. C. Burrows. 1959. Soil temperature and early growth of corn from mulched and unmulched soil. Soil Sci. Soc. Amer. Proc. 23:428-434.

Waksman, S. A., and F. C. Gerretsen. 1931. Influence of temperature and moisture upon the nature and extent of decomposition of plant residues by microorganisms. Ecology 12:33-60.

Waksman, S. A., and F. G. Teeny. 1929. Composition of natural organic materials and their decomposition in the soil, III. The influence of nature of plant upon the rapidity of its decomposition. Soil Science 26:155-171.

Walsh, L. M., and J. D. Beaton. 1973. Soil Testing and Plant Analysis. Pub. No. 2. Soil Sci. Soc. Amer., Madison, WI.

White, P. J. 1984. Effects of crop residue incorporation on soil properties and growth of subsequent crops. Austr. J. Exp. Agric. Anim. Husb. 24:219-235.

Whitting, L. D. 1965. X-ray diffraction technique for mineral identification and mineralogical composition. p. 671-698. *In* C. A. Black (ed.). Methods of Soil Analysis --Part I. Amer. Soc. Agron., Madison, WI.

Wilhelm, W. W., J. W. Doran, and J. F. Power. 1986. Corn and soybean yield response to crop residue management under no-tillage production systems. Agron. J. 78:184-189.

Williams, Jr., J. L., and G. A. Wicks. 1978. Weed control problems associated with crop residue systems. p. 165-172. *In* W. R. Oschwald (ed.). Crop Residue Management Systems. ASA Special Pub. No. 31. Amer. Soc. Agron., Madison, WI.

Willis, W. O., C. W. Carlson, J. Alessi, and H. J. Haas. 1961. Depth of freezing and spring runoff as related to fall soil moisture level. Can. J. Soil Sci. 41:115-123.

Willis, W. O., W. E. Larson, and D. Kirkham. 1957. Corn growth as affected by soil temperature and mulch. Agron. J. 49 323-328.

Zelazny, L. W., and F. G. Calhoun. 1971. Mineralogy and associated properties of tropical and temperate soils in the western hemisphere. Soil and Crop Sci. Fla. Proc. 31:179-189.

BIOGRAPHICAL SKETCH

Abdul Wahab Wafis was born on February 10, 1950 in Sungai Tukang Sidin, Teluk Intan, Perak, Malaysia. He attended his upper secondary school at Sekolah Alam Shah, Kuala Lumpur, Malaysia, from 1966 until 1969. In 1970 he was admitted to the National University of Malaysia, located in Kuala Lumpur, for his undergraduate studies and received the Bachelor of Science degree with a major in geology and a minor in chemistry in 1974.

Upon graduation he accepted a position with the Soil Science Division of the Malaysian Agricultural Research and Development Institute (MARDI) as a Research Officer. He was responsible for the soil survey and land use research project in KEMUBU Rice Irrigation Scheme, Kelantan, Malaysia. In 1976 he conducted an acid sulphate soil research project in MUDA Rice Irrigation Scheme, Kedah, Malaysia.

In 1977, he was admitted to the Soil Science Department, University of Florida for his M.S. degree (soil physics) under the supervision of Professor L. C. Hammond. His M.S. thesis entitled "Influence of Irrigation Strategy on Yield and Water Uptake by Corn and Peanut". He graduated in 1979. His M.S. fellowship training program was sponsored by MARDI/World Bank.

In 1979, he returned to Malaysia and continued his position as a Research Officer in the Soil Science Division of MARDI. He conducted a soil fertility and water management research project on sandy soils or known as 'Bris Soil' at Sungai Baging, MARDI Research Station, Kuantan Pahang, Malaysia. In 1980, he was promoted to a Senior Research Officer and in 1981 he became the 'Ketua Stesen' of Sungai Baging MARDI Research Station, an administrative post.

In late 1983 he was awarded a fellowship training program by MARDI to pursue a Ph.D. in soil fertility and management at the University of Florida and graduated in May 1987. After graduation he continued his service in MARDI.

He married Maimunah bt. Hj. Ali in 1975 and has a lovely daughter, Azantee Yazmin, and two handsome sons, Azrulreezal Azannce and Azrae Sharmal.

He is an active member of Soil Science Society of America, American Society of Agronomy, Soil Conservation Society of America and Malaysian Soil Science Society.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dr. J. B. Sartain, Chairman
Professor of Soil Science

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L. C. Hammond
Dr. L. C. Hammond
Professor of Soil Science

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Dr. F. M. Rhoads
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Dr. D. A. Graetz
Associate Professor of Soil Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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